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CHARLES D. WALCOTT, DIRECTOR

GEOLOGY

OF THE

NARRAGANSETT BASIN

BY

N. S. SHALER, J. B. WOODWORTH, AND A. F. FOERSTE

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Cambridge, Massachusetts, March 2, 1896.

SIR: I have the honor to submit herewith, for publication, a report on the geology of the Narragansett Basin. This report contains the result of a considerable amount of work done by me or under my direction since I became an officer of the Survey. In part, however, it is the result of studies undertaken before that connection was established. The object of the report is to set forth the results so far attained in the study of a field which presents singular difficulties in the way of its interpretation, and which will require the observation of many other students before it becomes thoroughly well known. Since the preparation of the report was undertaken I have been ordered to extend the results of a general nature there attained to other similar basins on the Atlantic coast. On this account it has seemed desirable to postpone a thorough consideration of many portions of the subject until other parts of the Atlantic coast have been examined.

I have the honor to remain, very respectfully, your obedient servant,

N. S. SHALER,
Geologist in Charge.

HON. CHARLES D. WALCOTT,
Director United States Geological Survey.

PREFACE.

As the conditions under which this report has been prepared are of importance as explaining the nature and scope of the investigations on which it is based, it is fit that they should be briefly stated. In 1865 I became interested in the geology of the Narragansett Basin, principally for the reason that it afforded a convenient district in which students from Harvard University could be instructed in certain problems of field geology which were not well presented in the neighborhood of Boston. A number of the fragmentary results thus obtained were published in several papers, but the greater part remained unpublished. With the extension of this desultory work a general idea as to the structure of the basin and its relations to some of its more important groups of strata was obtained. In course of time it seemed possible, with a moderate amount of labor, to prepare a memoir on the field which would add something to the body of information concerning the area.

About ten years ago, at the request of Maj. J. W. Powell, then Director of the United States Geological Survey, I undertook to devote the time which could be spared from more pressing duties to the task of completing this monograph. Experience soon showed that the mass of detailed work which remained to be done was so large that it would be necessary to associate other persons in the undertaking. To Dr. August F. Foerste was assigned the southern or bay section, and to Mr. J. B. Woodworth the northern portion of the field. The division of their work was not determined by a precise line, but was left to mutual understanding. Dr. Foerste's studies began in 1887. They were interrupted after a few months' labor, but were resumed in June, 1895, and the field studies were closed in September of that year. Mr. Woodworth has from time to time been employed in this field since June, 1891, but the work was discontinuous until the field season of 1895.

In allotting these tasks to Messrs. Foerste and Woodworth, I turned over to them the small share of the results that I had obtained in work on this field which seemed likely to be in any way helpful to them. Those contributions were, however, so limited in quantity, at least as regards the difficult matters of detailed structure, that the sections of this monograph which appear under their names are essentially their own.

A considerable range of facts, especially those which relate to the intimate structure and the metamorphism of the rocks, have not been to any extent treated in the following pages. This omission has been designedly made for the reason that the inquiries necessary to a consideration of these subjects would have required the services of a trained petrographer for a long time. In a like manner, the very interesting and important vegetable remains which abound in certain parts of the Coal Measures have been passed by, though they well deserved an extensive study. Thus it has come about that the extremely varied rocks which border the Paleozoic stratified series, or which are in the form of islands in its areas, are not discriminated according to their lithological varieties, but are indicated merely as pre-Carboniferous, and the paleontology of the basin, which includes extremely interesting groups of fossil insects and other organic remains, is in no wise presented. These and other omissions deprive this monograph of all claims to being a full account of the geological phenomena of the basin; it should, indeed, be considered as a contribution only to the stratigraphical and dynamic history of the area.

Where the statements of my collaborators are not questioned by me in footnotes, it should be understood that I approve of them as, so far as I can see, the best that can be made concerning the facts with which they deal. In only one instance has conference failed to bring about a concurrence of opinion concerning any question of moment. This is in relation to the value of the division which Dr. Foerste has termed the Kingstown series, which he regards as distinct from the Aquidneck, which overlies it. To my mind it appears to be only a local thickening of the last-named series, with a similarly local addition of sandstones. The disagreement is not only in relation to the propriety of separating these two sets of rocks, but also as to the thickness of the lower series. It seems to me most likely that the apparent increase in the depth may be reasonably explained by the occurrence of rather compressed folds, the axes of which

have not been identified, they being hidden either by the waters of the bay or by the drift covering which conceals the greater part of the surface of the islands. Nevertheless, as Dr. Foerste, who has given much time to the problem, remains convinced as to the distinct nature of this series, it is proper that he should express his convictions in his portion of the report. The matter is clearly debatable, with the probability that the truth is on the side of the observer who has the closest personal familiarity with the field.

It may here be observed that the conclusions of this report, so far as they relate to the general structure of the basin of which it treats, are most novel in the matter pertaining to the orogenic history of the field. The judgment as to the nature of the mountain-building work rests in part upon observations—in the main unpublished—which I have made in other somewhat similar basins that lie along the Atlantic coast from Newfoundland to North Carolina. The general proposition that the basins are characteristically old river valleys which have been depressed below the sea level, filled with sediments—the sedimentation increasing the depth of the depression—and afterwards corrugated by the mountain-building forces, will derive its verification in part, if at all, from study of other troughs of the Atlantic coast. It may, however, fairly be claimed that the facts set forth in this memoir show that this succession of actions has taken place in the Narragansett field.

The contributions to our knowledge respecting the value of the coal deposits of this basin are not so great as might well be expected from a careful study of the field. The truth is that the exploitation of the coal beds has been done in an extremely blundering manner, so that, while a large amount of money has been expended during the last hundred years, the amount of information which has come from it is very small and has little more than negative value. It may reasonably be hoped that the facts set forth in this monograph, and advice based thereon, will serve to prevent other profitless mischances in mining in this area, and make the next work which is undertaken decisive in its results as to the value of these very peculiar coals.

The first part of this report is limited to the discussion of certain general topics which could not well be treated in the special reports of Messrs. Woodworth and Foerste. This has necessarily led to a somewhat incom-

plete presentation of the problems which the basin affords. It should furthermore be noted that the party under the charge of the senior contributor is now engaged in studying other basins of the Piedmont or east Appalachian section of the coastal district. From these inquiries it may be expected that there will come a report concerning these peculiar features in the geology of this country. It therefore did not seem worth while to undertake a more systematic inquiry into the Narragansett field, which would demand a larger comparison with neighboring fields than it is possible yet to make. The reader may also remark the fact that there are but few diagrams in the text. Owing to the small and disconnected character of the sections which could be obtained in this basin, it has been found impossible to represent diagrammatically, in a precise way and for all parts of the area, the relations of the strata. Under these conditions diagrams are likely to have a fictitious value—to assert more than the facts warrant. So far as possible, the pictorial representation of the phenomena has been limited to local sections and reproduced photographs. It will also be noted that, particularly in Dr. Foerste's report, attention is called to a great number of localities which are cited in evidence of the conclusions to which the writer has come.

N. S. S.

GEOLOGY OF THE NARRAGANSETT BASIN

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VIEW LOOKING ACROSS THE UPPER PORTION OF NARRAGANSETT BAY.

The even sky line of the background is formed by the base-leveled crystallines with granite and infolded patches of metamorphic Carboniferous, forming the western boundary of the Narragansett Basin. The lowland in the basin is of early Tertiary date, the fiord of late Tertiary and Glacial age.

GEOLOGY OF THE NARRAGANSETT BASIN.

PART I.—GENERAL GEOLOGY.

By N. S. Shaler.

CHAPTER I.

POSITION AND SURFACE RELATIONS OF THE BASIN, AND THE ROCKS IT CONTAINS.

GENERAL FEATURES.

The field which in this monograph is termed the Narragansett Basin consists of a considerable area of stratified rocks ranging in age from the base of the Cambrian to about the later stages of the Carboniferous period. The eastern margin of this basin extends on its northeastern side to near the Atlantic coast in the neighborhood of Duxbury, Scituate, and Cohasset, or, in this section, to within about 6 miles of the sea. Its northern border, including the small Norfolk Basin in the area of Carboniferous rocks, lies in contact with the southwestern wall of what is commonly termed the Boston Basin. On the west the area is limited by relatively high lands which separate the trough from the Worcester syncline, a basin which owes its construction mainly, if not altogether, to mountain-building action occurring after the end of the Carboniferous period. On the south the Narragansett Basin is partially separated from the sea, at least in those portions of it which are above the water level, by a constriction formed of ancient, highly metamorphosed, stratified rocks and a variety of intrusions, together with some granitic areas which are probably of great age.

The north-south extension of the Narragansett Basin, including the related area of the Norfolk Basin, the axis of its greatest length, is from the southern portion of Narragansett Bay to near Walpole, a distance of about 50 miles. The east-west diameter, from the western part of Cumberland, Rhode Island, to the town of Scituate, Massachusetts, is about 30 miles. Although its outline has many irregularities, which will be hereafter described, the basin has in general a rudely curved form, concave on the southeastern side. The sections given in a later chapter of this report show that this trough has great depth, the lowest stratified beds disclosed on the margins possibly attaining in its central portions a level of from 10,000 to 15,000 feet below the plane of the sea. The sections also indicate that the correlative anticlines, at least those in the western and central parts of the field, probably had in their original form an elevation comparable in amount to the depression of the great trough which they inclose. In a word, the facts indicate that the mountain-building work effected in this district, and altering the original reliefs, was considerably greater, and gave rise to sharper foldings, than in the more interior parts of the eastern coast of North America, where the elevations still retain the mountainous character.

An examination of the structure and attitude of the rocks in this basin, as will be shown in a detailed way in the later sections of this report, indicates that this region originally contained an extensively developed series of pre-Cambrian rocks, the age of which is not yet determinable. They may for convenience be referred to that limbo of ill-discriminated formations, the upper Archean (of Dana), or Algonkian. Above and probably upon the eroded surfaces of these ancient strata, known in this report as the Blackstone series, there lie, apparently in detached, much worn patches, considerable remnants of the Olenellus horizon, or the lowermost stage of the Cambrian. On top of this formation and the granites which have broken through it, which were in turn much degraded, come the Carboniferous beds, strata which, owing in part to their great thickness and in part to their having escaped the nearly complete destruction which overtook the lower-lying beds, now occupy the greater part of the basin.

The evidence indicates that, on the western border of the basin at least, the margin of the field was determined before the beginning of Cambrian time. At the beginning of the Carboniferous, there is proof that

along the eastern border, from near the southern end of Aquidneck Island to Freetown, Massachusetts, a distance of 35 miles, a granitic area of considerable extent had already risen above the surface of the sea and was the seat of no little erosion. This is shown by the fact that along this line the rocks at the base of the Carboniferous section are made up mainly of granitic débris, the mass forming a characteristic arkose, at points so resembling the material from which it was derived that it appears at first sight to be the product of simple decay in place. Its age is sufficiently indicated by the numerous Carboniferous fossils disclosed by the pits which have been made in the mass in the search for fire clays. It is likely—though the evidence is less indicative than that just noted—that the eastern wall of the basin was in Carboniferous time continued northward as far as the neighborhood of Cohasset. The evidence is to a great extent from the drift, and is therefore subject to much doubt.

The condition of this basin in the beginning of Carboniferous time was apparently that of a broad trough penetrating far into the land and perhaps, though probably not, extending westward so as to include without break what is now the separated basin extending through the central part of Worcester County southward into Connecticut and northward to New Hampshire. The very coarse nature of the pebbly—or, indeed, we may term it cobbly—waste which occurs in the upper part of the Carboniferous, appears to indicate that the trough must have been shallow. This conclusion is affirmed by the tolerably uniform distribution of the pebbles, some of them a foot or more in diameter, across the basin on the line from Fall River to Attleboro.

On the assumption that the Narragansett Basin was shallow at the beginning of the Carboniferous period, and on the supposition that in the center of the field these beds attain a depth of several thousand feet, it seems necessary to assume that the orogenic work was in part accomplished during that time. The history of the basin can be best explained by the hypothesis of an extensive subsidence of the land within the limits of the trough as the beds which it contains were laid down, and a corresponding overlap invasion of the sediments, which constantly removed the shore lines farther away from the center of the basin.

After the close of the Carboniferous period the Narragansett district was evidently the seat of yet further mountain-building actions, which led

to extensive dislocation of the deposits and to the formation of several anticlines and synclines, as well as to the development of considerable fault movements. In this part of their history the rocks which remain in this field were probably deeply buried beneath accumulations which have been entirely swept away. This fact, as will be shown in detail hereafter, is indicated by the large amount of pebble deformation which has taken place in various portions of this field.

The foregoing statements make it plain that the detailed consideration of the Narragansett Basin should be preceded by some study of the stratigraphical and orogenic features of the district in which the basin lies.

STRATIGRAPHICAL AND OROGENIC RELATIONS OF THE BASIN.

The relation of the Narragansett Basin to the system of disturbances which have affected the eastern coast of North America involves certain questions concerning the organization of the Appalachian system which, so far as I am aware, have never been considered by the students of that field. Those mountains are generally assumed to consist in part of an ancient axis, which was developed perhaps by a succession of movements, partly in Archean and partly in early Paleozoic time, the whole forming a range extending from northern Alabama to the northern parts of New England, with a somewhat obscure continuation through Nova Scotia and Newfoundland to a contact with the old Labrador element of the Laurentian Mountains. To the west of the ancient axis of disturbance of the Appalachians, the Allegheny range or series of ranges has been recognized as a development which took place after the close of the Carboniferous, bringing about the formation of some score of considerable folds, all of which, except those in the extreme south, retain their relief. This Alleghenian division extends, with diminishing size of folds, as far north as near Albany, New York [1]

West of the Alleghenies, throughout their whole extent, from Alabama to the Mohawk River, there is a table-land which manifestly owes its uplift also to the orogenic work that resulted in the formation of the anticlines and synclines which were produced to the west of the old axis after the

[1] It is characteristic of the Alleghenian division of the Appalachians that it consists of prevailingly long folds, which are much compressed and generally lie in such a position that an east-west section of the field traverses four or five of the similar anticlines.

close of the Carboniferous period. This table-land is well exhibited in the plateau of central Tennessee, but is most strikingly shown in the degraded remnant of its northern part, known as the Catskill Mountains.

It has not yet been sufficiently recognized that to the east of the old Appalachian axis there was a great series of mountain ranges, now obliterated, which extended from the southern part of North Carolina along the Atlantic coast as far as Eastport, Maine. The reason why this portion of the system has been neglected is found in the fact that the structures which belong to it are peculiar in form and have been so far worn away that they present no considerable topographical reliefs. The region has the general character of a country which has been brought near to base-level, and the determination of the position of the ridges and furrows can be made only from the attitudes of the rocks. In fact, in the present state of our knowledge of this section of the country, only a few of the old troughs are recognizable and the position of the folds is not well made out.

Beginning on the south, we find the southernmost of these folds, so far as they have been recognized, in the Dan River Basin of North Carolina. Farther north, the Kings Mountain district appears to indicate the seat of another folding, a part of the rocks involved in the movement being so hard that they have not yet been completely eroded. In the Richmond coal field an extensive series of beds, probably of Triassic or Rhætic age, indicates the presence of another considerable basin, which has something like the area, depth, and general form of the Narragansett downfold. From studies of the Richmond Basin, made at various times, I have become convinced that the depth of the depression in its central parts probably exceeds 3,000 feet, and may be twice that amount, and that, in part at least, it is separated from the sea by an area of uplift which is now worn down to its granitic base.

To the north of the James River Valley in eastern Virginia the Triassic rocks are again found involved in relatively deep, broad troughs, the forms of which are not yet well made out. There are probably several of these troughs, some of which contain ancient stratified rocks of undetermined age that may belong in pre-Paleozoic time. From the Potomac River northward, owing to the mantle of Cretaceous and Tertiary waste, we have no distinct indications of this series of foldings until, in New Jersey, we again find the Trias involved in troughs. East of the Hudson the broad

trough of the Connecticut Valley may be regarded as in its nature essentially equivalent to the more southern basins, the only substantial difference being that on both sides it is bordered by a wide field of high-lying ancient rocks, which extends eastward nearly to Worcester and has a height that is not found in the case of the walls on the Atlantic side of the more southern basins.

At Worcester we come upon the most southern of the troughs on the eastern side of the central Appalachian axis in which well-determined Carboniferous rocks appear. The form of this basin is not well known, but, from what has been learned concerning it, it appears to be relatively narrow and long, having in general a closer resemblance to the synclines of the Alleghenies than any other of the troughs in the group which we will hereafter term the East Appalachians. The Narragansett trough is next in order, but, as it is to receive special treatment, it may here be dismissed with the brief statement that in its type of form and in the nature of its dislocations it differs from the West Appalachian or Alleghenian series of dislocations.

North of the Narragansett district we have in the Boston Basin a considerable downfold, the axis of which extends in a prevailing east-west direction, the depression having a characteristically great proportionate width and an irregular form which belongs to the other East Appalachian depressions.

From the Boston Basin northward the complicated and imperfectly known geology of the country indicates a succession of these basins distributed along the coast of Massachusetts, New Hampshire, and Maine to the New Brunswick district. One of these occurs at Newburyport; another is traversed by the Penobscot River; others lie between Mount Desert and the outer Cranberry Islands and to the north of the Mount Desert Mountains; yet another, or perhaps two partly separated basins, are to a great extent occupied by Cobscook and Passamaquoddy bays; still others exist along the coast of Maine, though their outlines have not been traced. The Carboniferous areas of New Brunswick and Nova Scotia appear to have been preserved in basins having the general character of the East Appalachian troughs

Reference has already been made to the decided differences in the forms of the folds which occur on the two sides of the old Appalachian axis.

Those on the west are narrow, relatively long, and consist, with slight exceptions, of simple foldings of the true anticlinal type. Those in the eastern or seaboard district are in general rudely oval in form, their length usually not exceeding twice their width. They are, in fact, broad troughs, the included strata being cast into a number of anticlines and synclines. This peculiar difference of form leads naturally to the supposition that the history of these two groups of depressions has been diverse. An inspection of the deposits verifies this supposition. It has already been stated that the Narragansett Basin was an ancient trough, formed before the Carboniferous period, in which, during a process of subsidence, the beds of the Coal Measures were accumulated. The evidence derived from the study of the Richmond, the Connecticut River, the Boston, the Mount Desert, and the Passamaquoddy basins has satisfied me that the troughs are of ancient date, that they were filled to a considerable extent with materials imported from the higher country about them, and that this filling process was associated with progressive local subsidences.

The foregoing considerations seem to me to warrant the supposition that the East Appalachian basins, or at least the greater part of them, were, in the beginning of their formation, erosion troughs, which became the seats of excessive deposition, and this brought about the lowering of their surfaces in relation to the original bed. In a word, they were downpressed by the weight of the burdens which came into them. At a subsequent stage the mountain-building forces, acting irregularly, compressed these troughs, producing the sets of local disturbances which are exhibited by each field. A possible instance of such local orogenic action in very modern times, as late as the Pliocene, is found in the tilted strata of the Marthas Vineyard district. In this case excessive deposition of a local character has been followed in turn, first, by subsidence, and then by compressive action, producing a large measure of folding, in a general way like that which has taken place in the neighboring Narragansett Basin, which lies immediately on the other side of the anticline that forms the eastern boundary of the Narragansett trough.

It should be said that the hypothesis of the antecedent erosion of the basins which we are discussing has a considerable measure of support from the very diverse orientation of the axes of the East Appalachian troughs. These range from east and west to north and south, a diversity which

seems to me to be inconsistent with the supposition that they have been formed through the action of such accurately determinate strains as produced the Alleghenian ridges. The last-named foldings are of the normal mountain type. The axes are parallel for great distances, and where the ridges change their orientation they preserve their parallelism and alter their general course with rather gentle curves. They exhibit no case of such contrast in the axes of the basins as is shown in the adjacent Narragansett and Boston troughs.

The known facts concerning the effects arising from the accumulation of thick sediments warrant the supposition that wherever this action occurs it is likely to be attended by a subsidence which, though of a local character, may attain an extent proportionate to the influx of the débris. Wherever along the coast line long-continued land erosion forms deep valleys, these depressions are likely to be, during a period of subsidence, the seats of extensive deposition. Where the amount of this sediment is sufficient to develop the downcast movement, it may lead to the formation of a trough of great geological depth, though it may at all times be shallow water or even retain the state of a delta area. It therefore does not seem a matter for surprise that the Atlantic coast district should exhibit basins of this nature, for, although this coast of the continent has been subject to many alterations of level, there is abundant evidence to show that from the Cambrian period to the present day the eastern front of the land has been often, indeed we may say prevailingly, somewhere near its present position. There has been ample time for the formation of many great coast erosion troughs and for their filling with sediments to the amount which the hypothesis requires. The final development of anticlines within the troughs in the extensive way in which they appear to have been formed may readily be explained by the existence of the same compressive tensions which have operated in the West Appalachian field, the difference being that in the East Appalachians the form of the troughs somewhat controlled the direction of these anticlines, while in the western portion of the system, a newly emerged part of the continent, they appear to have been guided in their alignment in a much greater measure by the direction of the compressive strains, there being no strong topographical features except the old land on the east to determine the trend of the upcurving.

At the present time, although the Atlantic coast of North America has

been subjected to recent and important alterations of level, there are many considerable basins along its shores which appear to be, in their structure and history, much like those which, according to the hypothesis we are discussing, were developed along this coast line during the Carboniferous period. Albemarle and Pamlico sounds, and the bays of the Chesapeake and Delaware, need only a continuance through a considerable extent of geological time of the conditions which now exist to bring about the formation of accumulations essentially like those under consideration. So, too, certain basins along the Gulf of Mexico, particularly Mobile Bay and the trough of the Mississippi, are the seats of extensive estuarine accumulations which in the ages to come may take on much the same aspect as the Narragansett Basin.

A little consideration will show the reader that a river valley in its lower parts naturally becomes the seat of sedimentation. An inspection of the maps of shore lines will make it plain that more than half the great rivers of the world have the lower parts of their valleys flooded in a way which clearly indicates that these estuarine regions have recently been brought beneath the level of the sea and thus converted from fields of erosion to those of deposition. The generality of the fact that the great rivers, notwithstanding the evident tendency to accumulate delta deposits about their mouths, enter the sea through their own submerged valleys, is probably in many cases to be accounted for by the fact that, while the continental masses as a whole tend rather constantly upward, their shores, being near the seat of maximum sedimentation, naturally tend downward, in the manner now recognized as resulting from the imposition of a great load of sediments on any part of the earth's surface. We may therefore regard the occlusion of river valleys by excessive sedimentation, which takes place coincidently with the subsidence of the trough below the level of the sea, as a normal feature in the history of any shore which is intersected by river valleys.

If the hypothesis which is here adduced to explain the main peculiarities of the East Appalachians be established, it is clear that, considered from the point of view of their origin, we must accept a new specific group of mountains, one characterized by features in the main determined by the fact that the beds of which they are composed have been laid down in a formerly existing erosion basin, originally due to stream work, though it may

have been orographically deepened by the subsidence caused by sedimentation. It will be seen that this view has a certain superficial resemblance to the hypothesis commonly known as James Hall's, in which mountains are explained by supposing, first, the accumulation of a thick series of beds; second, a subsidence of the crust, due to the deposits, bringing about a folding of the beds; third, a massive uplifting of the foundation on which these foldings rest, so that the ridges come to stand on a lofty pedestal. I would not have it supposed that there is any real similarity between these hypotheses. The essential difficulty of the hypothesis which endeavors to explain the formation of mountains first by subsidence and then by elevation, is that there is no sufficient means indicated whereby the reelevating process can be brought about. There is also much reason to question whether the downsinking movement could develop the arches of the strata. In the view which I am advocating, the conceptions are much more simple and rest upon more patent facts. The steps of action which are postulated are as follows: First, the excavation in ancient and compact rocks, in their nature good transmitters of thrusts, of a trough or basin such as is likely to be formed in the estuarine section of a considerable river; second, the filling in of this basin by sediments accumulated during a downward oscillation of the area in which the basin lies; third, the development of compression strains, such as are involved in rock folding, the relief being afforded by the folding of these stratified deposits.

If this hypothesis as to the origin of the Narragansett foldings were correct, we should expect to find the maximum of disturbance in the extreme margins of the basin, the central features of the area remaining less disturbed. As will be seen from the chapters on the deposits of the basin, this is essentially what we find. Wherever the area is of sufficient width to afford a field for the development of the structure in a clear way, we observe that the indications of lateral stressing are very clear in the belts of country next the contact with the crystalline rocks, while in the central portion of the field the beds exhibit lessened stress. Thus, as will be seen from fig. 1 (p. 19) and the sections across the basin where the distance is not far from 20 miles, we find the marginal portion of the stratified rocks exceedingly flexed, the resulting dislocation attaining about the highest order of complexity, while the intermediate field, including much more than one-half the whole length of the indicated line, is less marked by the stressing forces.

Where the Narragansett Basin narrows, as it does in the southern third of its length, the type of the folding differs somewhat from that above indicated. In place of the folds on either side, with a less disturbed middle field, the whole of the section is folded into a few great trough-shaped undulations, with some minor irregularities. Yet the fact that the strains entered the bedded rocks from the sides is shown by the character of the bottom of the great North Aquidneck syncline. The form of this part of the basin is tolerably well known by the mine workings in the northern part of Aquidneck Island. These explorations show that the central portion of this area has in a measure escaped the disturbing influences which have perturbed the beds next the margins.

Besides the evidences of stress which are shown by the extensive dislocation of the stratified rocks of the Narragansett Basin, we must note the equally characteristic marks of compression afforded by the interstitial movements which the rocks have undergone. These changes of position of the rock materials are exceedingly common in the metamorphic part of the field (see fig. 6, p. 120) and for a short distance to the eastward, and are readily observed wherever there are any data by which they may be judged. Wherever the rocks lying near the eastern and western margins of the basin contain organic fossils or pebbles, save of quartz, a slight examination will in practically all cases show that those bodies have been more or less elongated, the direction of their extension usually being on horizontal lines which are approximately parallel to the neighboring margin of the basin. At many points it is evident that the elongation of the pebbles or fossils has been as much as 50 per cent of their original diameter on the given axis, and sometimes it exceeds this amount. It commonly happens that the distortion was sufficient to convert a circular disk lying in the axis of the movement, and having a diameter of a foot, into an ellipse having a major axis of 2 feet and a minor axis of 6 inches. In rare instances the alteration of form appears to go much beyond this proportion. I suspect, indeed, that at a few points it is obscurely traceable to three or four or even five times the original length, but in these higher terms of the series fossils become mere blurs and pebbles lose all semblance of their original character.

Although solid bodies like quartzite pebbles may often be found stretched to the amount of 50 to 100 per cent, it is generally easy to see

that the matrix in which they are embedded has been much more extended than the more rigid inclusions. This is shown by the fact that near each end of the axis of the pebble in which the elongation has taken place there is often a slickensided surface, showing that the matrix pulled away from the sides of the stone and slipped by them, while at the very end we note the existence of a vein deposit which is also slickensided after the manner of most veins, the structure showing that the movement which pulled the matrix away from the inclosed fragment operated slowly and by successive steps. It often happens that pebbles, especially those of large size and of the more rigid varieties of stone, show no distinct signs of elongation, and yet they have these appended veins and the slickensides, indicating that the more plastic matrix has yielded to the pressure which has been imposed upon it.

There are certain features in the distribution of elongated rock masses which appear to throw some light on the questions we are now considering. In the first place, we note that in the Narragansett Basin, and, so far as my observations go, in the other basins of the East Appalachians as well, the plastic migrations of the strata, as shown by the distortion of fossils and pebbles, are decidedly more common in the marginal parts of the several fields. These elongational phenomena are strikingly manifested at many points in the southern portion of the Narragansett area. In the central part of the area there are extensive tracts of conglomerate where a close examination has failed to indicate either that the pebbles were stretched or that the matrix was forced by these inclusions. This goes to show that the force which affected the stratified rocks came upon them as a thrust horizontally transmitted from the field of crystallized rock on either side.

The other point concerns the regional distributions of plastic migration of rock. This phenomenon seems to be of common occurrence in the East Appalachians from New Brunswick southward. It is excellently shown at the Cobscook Basin, about Mount Desert, and in the Boston Basin; in the basins to the southward it is more scantily exhibited. Curiously enough, however, this feature appears to be prevailingly lacking in the rocks of the West Appalachians, notwithstanding the deposits of that section appear to have been on the average about as much dislocated by folds and faults as have those of the eastern section. It is not clear to what the greater plastic movement of the eastern rocks has been due. It may, however, be suggested that such movements depend upon the compression of rocks while

under a deep cover of overlying strata and therefore at temperatures which would in a large measure diminish their rigidity. This does not seem a satisfactory explanation, for the reason that while the amount of strata which has been removed from these eastern mountains has probably been larger than is the case with the western ranges, the erosive process, at many points in the west, has gone far enough to reveal the bases of the anticlines and synclines, even as it has done along the Atlantic coast. It has been noted that the eastern basins are generally, except perhaps that of the Dan River, much more intersected by dikes and stocks than are those of the west, where there are but few such intrusions known, perhaps in all not over a dozen between the Catskills and Alabama, as against the thousands which may be traced in the mountain-built area of the Atlantic coast.

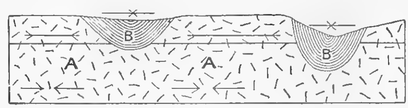

FIG. 1.—Diagram of assumed conditions of compressive strain in rocks in a basin of accumulation. AA, massive crystalline rocks. BB, the rocks of the basins. The arrows indicate the direction of the compressive strains; the spaces between their heads indicate the measure of the yielding at the several points.

It seems reasonable to assume that the extensive plastic movements of the rocks in the East Appalachian district are related to the igneous action which has occurred in this field, and that the two groups of facts show that the modes of action of the mountain-building forces in the two districts were in some ways very different. I venture to suggest that the difference was partly due to the conditions of the superficial rocks in the two fields. In the west the surface of the country from northern New York to Alabama was, at the time of the elevation of the West Appalachians, again occupied by relatively unbroken strata which lay on the surface of the upper Paleozoic rocks. The stresses of compression which assailed this wide field when the conditions of resistance were uniform affected all parts of it in an approximately equal degree. In a limited way, in northern Alabama, Georgia, and Tennessee, where the conditions were diversified, the stresses, as shown by Hayes, were in some cases locally accumulated and so discharged as to bring about extensive overthrusting; but in general the folding was approximately equal for each unit of the section which was stressed. There was, in a word, no transfer of thrust through great beams of massive and therefore unyielding rock to fields where the stress could take effect on the easily folded strata. On the Atlantic slope, however, the conditions led to the local intensification of the stress phenomena. Between the deep basins,

filled with their bedded rocks, lay fields of crystalline materials which had been compacted by previously administered pressures and the accompanying metamorphism until they had been brought to the most rigid or the best thrust-transmitting state to which rocks may attain. The result was that the compressive strains were transmitted through these ancient close-knit blocks of strata to take effect on the frailer materials which were inclosed in the troughs between their edges. The assumed conditions are in a diagrammatic way represented in the accompanying figure (fig. 1).

RESULTS OF THE ACTION OF OROGENIC FORCES.

So far as can be determined by the evidence which has been found, the orogenic movements which flexed and fractured the Carboniferous rocks of the Narragansett Basin did not affect in a similar manner the more ancient formations which border the area. There are, it is true, certain faults intersecting the margin, particularly on the northern side of the area, which cut through the Carboniferous beds and the fundamental complex alike, but there is no evidence that these faults extend very far beyond the margin or that folds attended the formation of the rifts. Any system of anticlines and synclines affecting the more ancient beds would, we may fairly presume, have left their marks in the distribution of the deposits as they appear on the present surface. The several groups of metamorphosed beds would appear in parallel bands, an arrangement which they do not exhibit.

The only distinct feature in the ancient compact rocks which can be attributed to compressive action is the system of shearing planes which have been extensively developed in the massive rocks on the margin of the basin. Where these have been developed in the granitic rocks they have given the latter a gneissoid aspect. These secondary structures are most distinctly marked near the contact borders on the east and west, and appear to diminish as we pass a few miles from the present margin of the Carboniferous field. The existence of this class of distortions in the rocks, along with the general lack of evidence of folding, points to the conclusion that the pressure affected these compact formations in a way different from that in which it affected the stratified beds of the basin. It may be that the yielding in the interstitial movements accomplished a certain reduction in the length of the sections even when the materials were too rigid

to permit them to take on the normal folds which afford the natural means of shortening in stratified beds.

Since the shearing planes of the massive rocks grow less evident as we go away from the margin of the basin, and have not been clearly observed beyond the limits which are likely to have been occupied by its deposits, the question arises whether these planes are not a consequence of the movements which must have occurred in the rocks that lay beneath the Carboniferous strata at the time they were folded. That some form of distortion affected these basilar deposits must be assumed, but the precise nature of the movements is not known.

The type of folding exhibited in the stratified rocks of the basin is clearly that of ordinary synclines and anticlines which have been carried to a rather advanced stage of development. As will be noted from the maps, the axes of these folds trend nearly north and south in the southern portion of the basin, but in the northern part they incline to the eastward, and in the east attain a position nearly at right angles to the southern folds. This turn of the structural axes seems to be due to the existence of the broad eastern bay, which is a notable feature of the basin.

There is another noteworthy feature in the form and distribution of the anticlines which appears to be closely related to the peculiar history of this basin; this is clearly exhibited in the accompanying diagrammatic section (fig. 2, p. 27), which shows the attitudes of the folds in the central part of the field along a line from north to south. In this section the compressive action has operated to create strong folds next the borders of the basin. These folds have their steepest slopes toward the margin, the sides toward the center of the basin being much less inclined, so that by erosion of the declivities of the anticlines on either side a relatively broad trough is formed in the central part of this field. So far this relation of the slopes of the upper folds to the margins of ancient massive rocks has been distinctly traced only in the northern half of the mountain-built district, but there are indications that it exists also in the southern portions of the field, being there concealed by the waters of the bay or masked by the prevailing covering of drift.

The disposition of the strata as above noted appears to require the supposition that the thrust acted from either side in such a manner that the central portion of the basin was a relatively neutral zone in the vaulting

movements. If the strain which produced the folding was of equal value in all parts of the basin, there would be no reason why the resulting arches of the strata should not have been of uniform declivity on either side. I can best account for the facts in this case by supposing that, while the contraction which brought about the mountain building may have acted in all parts of the field, a large part of the stress was carried through the lateral girders of indurated massive rocks on either side of the basin until it could be applied to the newly formed, distinctly layered, and therefore less resistant materials contained in the old Narragansett Basin.

The horizontal value of the movement which was taken up in the foldings of this field can not as yet be accurately computed. The attitudes of the beds, however, indicate that it amounted to 2 miles or more. The conditions of this action may be considered as such that the surface of the central part of the disturbed area may not have been moved except downwardly, while the longitude and latitude of the points on the surface on either side which were affected by the foldings were evidently changed in an increasing measure as we depart from the central axis.

The depth of the distinctively stratified rocks in the basin at the time the mountain-building work was done can not well be reckoned at less than that of the existing section, but as this region has been subjected to an amount of erosion competent to bring the anticlines and synclines to about the same level, it may well have been near double that amount. Therefore we may assume the depth of the section of massive rocks which conveyed the thrust from an extreme area on either side to the deposits of the trough as not less than 2 miles.

It is not yet clear whether the mountain-building action which has affected this basin was altogether accomplished after the latest-formed beds which it now contains were accumulated. The fact that all the sections of the Carboniferous series were accumulated in shallow water, or but little above its level, requires us to suppose that the trough was the seat of a nearly continuous depression. It is to be expected that the downsinking would have been accompanied by some measure of compressive movement. So far, however, the field has afforded no evidence of such mountain-building work done during the subsidence of the trough. On the contrary, the observations are most reconcilable on the supposition that the whole of the strictly orogenic action took place after the work of depression was

complete. In fact, it can not be believed that there was any distinct relation between these two movements—that of general downsinking and that of warping under the influence of the lateral thrusting.

It may be noted that the conditions of mountain building in this basin resemble in a general way those of the Appalachian district, with the exception that in the latter region the neutral axis appears to have been in the line of the ancient belt of the Blue Ridge or its equivalent ranges to the north and south. Against this central ridge the thrusts apparently came from the east and west. Moreover, in this Appalachian field the compressive action seems to have been distributed over a much wider section, with the result that the amount of deformation per unit of length in an east-west direction was much less than was the case in the Narragansett Basin. The folds are, on the average, less crowded together, and the synclines are wider; in other words, the evidence goes to show that, in proportion to the size of the disturbed area, much more movement was taken up in folds in the Narragansett Basin than was the case in any part of the West Appalachian field of disturbances.

The relation of the mountain-building work of the Narragansett Basin to similar action in the neighboring fields is a matter of much interest. There are three of these areas that deserve special notice—the Connecticut Valley, Marthas Vineyard, and Boston Basin. Of these three regions of mountain-building action, the one most remote—the Connecticut—is in all respects the most unlike the Narragansett Basin in its orographic features. In the Connecticut Basin we have what appear to be the same general antecedent features noted in the Narragansett Bay. There was a preexisting valley, which was deeply and rapidly filled by detrital materials. It is likely that this accumulation took place during a period of subsidence; it evidently occurred after the deposits of the eastern trough had been formed, and under conditions which led to the extravasation of large amounts of lava. When the Connecticut Basin was subjected to compressive action, the yielding was by the rupture and shearing of blocks, with little trace of folding. It seems most probable that the hypothesis adduced by Prof. W. M. Davis—which is, in effect, that the easily fractured planes of the basement rocks of the area, which are composed of schists standing at a high angle, induced the formation of faults rather than folds—accounts for the departure of this region from the type of mountain building else-

where to be observed in the New England troughs. In a measure, the distinct folding of the neighboring trough deposits on the east, occurring where the basement beds are of an essentially nonschistose character, seems to bear out this hypothesis.

In the Marthas Vineyard area of distortions there is no indication of a trough. There are no ancient rocks rising above the plane of the sea. It is, however, quite possible that the northwestern border of the basin, if we assume such to have existed, was in the bed rocks of the neighboring mainland and that the seaward border has been worn away by marine action or lies depressed below the sea level. It is to be noted that the prevailing axes of the dislocations on Marthas Vineyard indicate a pressure acting from the northeast and southwest, with resulting foldings which are mainly aligned in a northwest-southeast direction, or approximately at right angles to the usual trends of the Narragansett and other folds of this part of the continent. Although it seems to me probable that these crumplings of the Cretaceous and Tertiary beds of Marthas Vineyard were formed in a trough which was filled in these ages, the evidence on this point is not clear. So, too, with the dislocated deposits of Block Island. It will therefore be best to pass these areas by with the remark that the forms and trends of their orographic reliefs differ widely from those of the older disturbances, and that some of their peculiarities, especially the faultings and complications of their folded strata, may be due to the fact that the movements occurred near the surface, without the restraint which is imposed on beds, such as those in the Narragansett area, compressed while under a thick mantle of deposits which have since been removed.

In the Boston Basin we find series of rocks which have the same general character as those in the Narragansett Basin. To a great extent, the rocks, as regards their structure, are fairly comparable to those in the Narragansett district. Although the evidence is not perfectly clear, it goes to show that there was the condition of a preexisting basin, which was formed sometime after the horizon of the pre-Cambrian, and which received the deposits of the Roxbury conglomerate period, which make up the greater part of the accumulations. As yet the age of these conglomerates and the associated rocks is not determined, a most assiduous search having failed to reveal fossils of determining value. Therefore it is not possible to fix the earlier limit of the disturbances. Still, the immediate contact of the

basin on the north and south and the approximate parallelism of the axes of their foldings appear to indicate that the strains took effect on them at approximately the same time.

Complicated as is the structure of the Narragansett Basin, that of Boston Bay is yet more involved. Although some minor folds may be traced in it, and larger arches are fairly to be assumed, the area as a whole appears to be much less massively and continuously flexed, and more faulted, than that on the south. It is, moreover, far more generally penetrated by dikes than is the Narragansett field. Its type of structure seems to be between that of the last-named basin and that of the Connecticut. It is probably owing to the relatively deep erosion of the Boston Basin and the large amount of faulting in the orogenic work that it is so difficult to recognize and determine the elements of folding which have existed.

OVERTHRUST PHENOMENA.

The phenomena of overthrusting which occur in the development of mountain dislocation have of late been the subject of much profitable inquiry. It is therefore worth while to examine into the question of their occurrence in this basin. As will be noted in the sections, the only portions of the field where accidents of this nature seem to be indicated are in the district extending from near Providence to the northern boundary of the basin. The reason for this may be that only in this part are the attitudes of the rocks near the margin sufficiently disclosed to make a close interpretation possible. Particularly in the region about the Attleboros the positions of the dislocated strata favor the view that the beds have been at first folded and then thrust over, usually toward the less-disturbed centers of the stratified rocks, so that a certain amount of migration of the beds has been brought about. How far this has led to the disruption of the folds, so that the masses which have changed place have been rent away from the beds of which they originally formed a part, can not be determined from the data now in hand.

It is probable that the original margin of the Carboniferous rocks in this basin was farther away from the center than it is at present. The process of erosion, which has attacked the massive crystalline rocks of the boundaries as well as the stratified interior parts of the trough, has most likely lowered the whole of southeastern Massachusetts to the extent

of several hundred, perhaps to the depth of 1,000 or more, feet, the result being that, as the old bordering walls had an erosion slope, the margin is at present perhaps some miles nearer the center than it was when the folding was done. It has also been noted that the folding and other evidences of stressing which the rocks present diminish, except on the northern border, as we pass from the margin toward the interior of the Carboniferous area. These considerations lead us to see that the portions of the beds which were most dislocated have been removed by the erosion process, which, as is shown by the planed-down character of the surface, has undoubtedly been very active in this part of the continent. It is therefore not unlikely that great migrations of strata took place at the time of the disturbance, the indications of which have been entirely lost to us by the process of decay and removal of the beds which were involved in the movements. In a word, the zone where we might most naturally suppose the overthrusting actions to have taken place has in large part disappeared, at least so far as the superficial beds are concerned.

From the conditions presented by this basin there is reason to believe that the rupture and horizontal displacement of folded strata would be more likely to occur here than in the ordinary instances of mountain folding. Under the usual circumstances, where the contracting impulse affects a large extent of country, influencing all the rocks alike, the relief effected by the corrugations of the strata is apt to be equal in all parts of the area subjected to the movement. When, however, as in the Narragansett district, the strains were most applied on the margins of the field, where the tensions developed in a wide extent of country were localized in a narrow zone of relatively weak strata, we must expect the highest type of distortion and rupture that occurs in mountain-folding work.

Such overthrusting as has occurred in the Narragansett Basin appears to a great extent to have been begun by folding, the arches being raised to a considerable height. These arches appear to have collapsed, as all compressed arches tend to do.

Overthrusting action appears to be most probable in the region between the villages of North Attleboro and South Attleboro, where the relation of the red Wamsutta series to the gray rock on the south requires the supposition of this movement. So far as has been observed in the few traceable

faults, there is no tendency of faulted blocks to ride over one another. It can readily be understood that, inasmuch as this region has been subjected to very extensive erosion, overthrusting which was preceded by the collapse of the folds might have all the marks of its former existence destroyed by the removal of the strata which were involved in the movement.

An ideal section (fig. 2) drawn by Mr. Woodworth through the three great synclines in which the Dighton group appears, including the Attleboro syncline on the north, the Great Meadow Hill trough in the middle of the basin, and the Swansea syncline on the south, exhibits a symmetry in the cross section which is further evidence of the simplicity of the larger features of structure of the central part of the basin. There is along this line of section a great broad syncline in the middle of the basin. It has nearly symmetrical slopes with relatively low dips. The synclines parallel

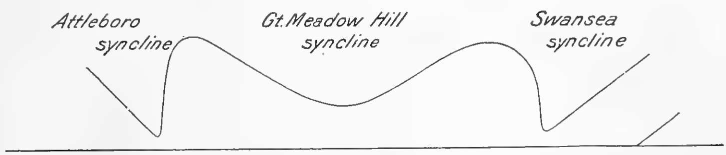

FIG. 2.—Theoretical plan of the great folds of the Narragansett Basin.

with it on the north and south have their axial planes inclined away from the middle syncline, or, in other words, the sides of the synclines facing the middle area are nearly vertical. A plane lying in this region of folding would have been deformed so as to give a cross section like that in fig. 2. There is in this case no prevailing pitch of the axial planes to or away from the ocean or an older land mass, but rather a symmetrical deformation of beds with reference to the middle line and sides of the basin as it now exists.

DIKE ROCKS OF THE BASIN.

Although, as before stated, the systematic study of the igneous rocks of this area has not been undertaken, there are certain features connected with their distribution which deserve notice. These concern the areas in which the intrusions occur and the portions of the great section which they traverse.

So far as has been observed, all of the numerous intrusions occur on the marginal portions of the basin, mainly on its western side and in the prolongation of the area in what is known as Norfolk Basin, a field which, as elsewhere noted, is not much considered in this report. The eastern margin of the area is not so well revealed as the western, but, as will be seen in the detailed descriptions of Messrs. Foerste and Woodworth, with the exception of the felsite dike in Plympton, no intrusive masses have been discovered on this margin. Dikes also occur, as indicated in Dr. Foerste's reports, on the southern portion of the field, but not so abundantly as on the western versant. So far as the observations go, they make it improbable that, in general, any dike attains the surface at a point more than 2 miles toward the interior from the border of the Carboniferous field. An exception to this statement must be made in the case of the Wamsutta field, where, perhaps owing to the large amount of disturbance the beds have undergone, dikes are found at a distance of nearly 4 miles from the western border.

It may also be remarked that the extended study of the rocks in the central portions of the area has shown that, while dikes may perhaps have penetrated to the lower parts of the section, there is no evidence afforded by the bare rock surfaces, or by the materials of the drift so far as observed, which would lead to the supposition that these injections penetrated into the zone of the upper conglomerates.

Perhaps the most interesting group of what appear to be intrusive masses is that of the pegmatites which occur in the southern portion of the western margin. As we go southward from Providence there is a gradual increase in the measure of metamorphism to which the Carboniferous strata have been exposed. The observer is led to suspect the existence of some extensive concealed intrusion which has applied much heat to the section. These indications of metamorphism increase until they attain their maximum in the portions of the field in and about Boston Neck and Tower Hill. Where the alteration of the strata is most considerable—where, indeed, those beds appear as ordinary gneisses—we find extensive pegmatite intrusions, which penetrate these conglomerate and sandstone gneisses. I have been unable to determine whether these intrusions are to be classed as dikes or as veins. So far as observed, the facts hardly warrant the assumption that the metamorphism is directly due to the incoming of the

pegmatites, but rather lead to the supposition that these last-named deposits have been derived from some large granitic mass intruded into the basement rocks of the section, though at no point exposed on the surface.

The facies of the beds in the region about North Attleboro makes it appear not unlikely that volcanic action may have taken place in this portion of the field.

CHAPTER II.

PHYSICAL HISTORY OF THE BASIN.

RELATION TO MARINE AND ATMOSPHERIC EROSION AND DEPOSITION.

It may well be noted that the degree to which shore land basins, such as we are now considering, are developed is in general determined by the amount of time during which a given coast line has remained in about the same position. It is not to be supposed that the coast level remains enduringly the same, but rather that in the repeated oscillations the sea does not long desert a given field. During the periods when the area is relatively high the rivers in the lower part of their courses have a chance to develop those wide valleys of gentle slope which are characteristic of regions that have attained very nearly to the general base-level of erosion—i. e., the average position of the sea during its endless variations in height. In general it may be said that wide valleys next the shore are the best possible indications of a relatively long continued preservation of coastal conditions in the region where they appear. The Atlantic coast of the Americas affords numerous examples of these broad, nearly base-level valleys, which have been formed at divers times in its history. As the existence and the number of these valleys have a distinct bearing on the problem in hand, it is worth while to give a brief general account of them, at least so far as North America is concerned.

Along the Gulf of Mexico there are half a dozen of these considerable troughs, of which those of the Mississippi and Mobile rivers are the most characteristic, or at least the best known. Both of these valleys, and probably the other basins along this coast, are, at least as regards their lower parts, of relatively modern origin, dating probably from Tertiary times. On the Atlantic coast, to the north of Florida, there are again a number of these lately formed basins, of which those of Albemarle Sound and Chesapeake and Delaware bays are the largest and most characteristic.

North of Delaware Bay, and thence along the coast to Greenland, the number of distinct coast erosion troughs increases and the evidence of their great antiquity is very clear. The position of the Newark deposits in the Connecticut Valley makes it evident that this region was an eroded basin as far back as the Triassic period. The Narragansett Basin owes its excavation to actions which antedate the Carboniferous. The Boston Basin, and several others to the northward along the shores of Maine, may be dated back to the Paleozoic age. Yet farther northward, wide valleys of the coastal-plain type, though now deeply submerged, are indicated by the reentrants of the Bay of Fundy, the Gulf of St. Lawrence, and probably by the great system of embayments of the Arctic realm, the Greenland Straits and Hudson Bay, as well as by a host of lesser indentations, which probably mark the seat of long-continued or, rather, frequently repeated river action interrupted by periods of marine invasion.

It will be observed from the statements made in this report that the Narragansett Basin has at present an average structural depth of probably not less than 7,000 feet and a maximum depth of 12,000 feet; that is to say, the downfolded Carboniferous rocks and the beds which lie beneath them attain, at the base of this incline, a position at least the last-named distance below the present sea level. The question arises as to how much of this geological depth is due to erosive work on the rocks of the area and how much to actual depression preceding or connected with the folding of the strata. If the basin originally had anything like its present depth, we should have to suppose a very great change in the position of the coast line. If, on the other hand, we may assume, as is done in this paper, that the basin, as regards its geologic depth, is mainly the product of folding, and that the movements are probably due in the main to the accumulations of deposits, then the original depth of the basin may have been slight.

The evidence seems to show that the coastal basins of the Atlantic shore owe their depth to three more or less associated actions—to river erosion, to downflexing and faulting associated with the accumulation of strata during periods of subsidence, and to the massive swing of the continent in those large deformations such as have taken place in recent times, with the consequent invasion of the sea into the valleys. Two of these actions are local in their nature; the third involves continental or perhaps wider conditions.

It should be said that the mainspring of the development which has taken place in these basins is the crustal strain which manifests itself in mountain building. Where this strain, as in the ordinary conditions of mountain growth, such as existed in the West Appalachians, takes effect on uniform, horizontal, little eroded strata, the action appears to result in the formation of elongated, more or less accurately parallel ridges, such as are exhibited in the Jura or the Alleghenies. Where, on the other hand, as along the Atlantic coast, the crust is composed of ancient massive rocks in which deep valleys have been excavated, the orogenic strains result in the deformation of the patches of stratified rocks which may have been accumulated in the great valleys during the periods of subsidence.

The dislocations of the Atlantic coast basins clearly indicate that the stress which has caused them was what we may term quaquaversal—that is to say, it has acted in several directions around the greater part of the horizontal circle. This behavior of the crustal stress is quite different from that which we find exhibited in normal mountains; there, as before remarked, the relief has been obtained by the formation of ridges and furrows, the axes of which are nearly parallel to the same great circle. Although the amount of this parallelism has usually been much exaggerated, there can be no doubt as to its substantial existence. However, it seems unwarranted to suppose that the axial relation of the ridges is due to the existence of a strain acting in but one direction. All that is required to produce the result is either a certain predominance in the value of the strain in a particular versant, or, what comes to the same thing, a greater tendency to yield along one set of lines. Instances of this may frequently be seen in the wrinkling of veneers or in sidewalks which have been covered with some plastic materials. With a simple device the cream on a pan of milk may be made to show the effects of the same general principle, where the giving way takes place rectilinearly, though the difference in pressure in the several axes of the circle is but small. Moreover, even in the most nearly parallel mountains, there are generally to be found cross folds which show very clearly that the strain has not been uniaxial.

The foregoing considerations lead us to infer that the diversity of axes in the elevations produced in the singular group of antecedent basin folds which we are considering has not been brought about by a class of strains differing as regards their distribution from those involved in the formation

of ordinary mountains, but rather through the opportunity which these diversely shaped and irregularly disposed basins have afforded for the varied application of the stresses.

As before noted, the evidence derived from the geological history of southeastern Massachusetts and the neighboring portions of the shore to the northward as far as the Gulf of St. Lawrence, and to the southward into the Carolinas, shows that while this coast line has been subjected to repeated and considerable variations of level, it manifests an equally clear tendency to return to about its original position. Beginning with the Cambrian time, we find reason to believe that this region was coastal at the outset of the Olenellus epoch. If the rocks of the Roxbury conglomerate be of the Potsdam period, the same was true at the last of the Cambrian stages. It is again the case in the Carboniferous, in the Trias, the lower Cretaceous, the middle Tertiary, and at the present day. Evidence found on the coast of Maine indicates that the coast in that part of the field was also near by in the Devonian period. Thus, in eight or nine of the great periods, well spaced through recorded geological time, we find the coast of this district near to its present attitude. As the action of erosion during the periods of elevation, and the accidental burial beneath later deposits of portions of the strata, are likely to have obliterated much of the record, the point which we are endeavoring to make appears to be well affirmed. This point is of evident value in the present inquiry, for it serves to show a reason why extensive erosion valleys are characteristic of the Atlantic coast. In those phases of the coastal movement in which the land has been above the present level of the sea, there has been an opportunity for the formation of extensive valleys of erosion, which, from time to time, with the downsinking of the shore line as a whole and the downward warping, concomitant with the extensive deposition, have had a chance to take on their present peculiar character.

In this connection it should be noted that the usual tendency of shore-line changes on the periphery of the continental fold is to return the coast after each considerable oscillation to somewhere near where it was before. Elsewhere, more than once, I have called attention to the facts that within the ordinary growth of the great corrugations on the earth's surface the movements are normally those of downsinking of the ocean floors and uprising of the emerged portions of the continental mass, and that this

movement is essentially like the rotation of the lever about the neutral or fulcrum point, which is ordinarily near the shore line. On the doctrine of probability, it is more likely to fall at the contact of land and sea than at any other point in the length of the rotating area. If the land advances from the ancient shore, the natural result is an increase in the amount of erosion and consequently of deposition off the given coast line. This, in turn, as an effect of the loading, tends more sharply to depress the region next the coast, and so, in time, to a return of the shore toward its original position. If, on the other hand, the sea invades the land, considerably narrowing the field of erosion, the supply of sediments is checked and the element of accumulating weight which makes against the uprising is proportionately lessened, with the resulting tendency of the district to ascend in the next adjustment of the crustal stresses which are involved in continental growth.

So far as I am aware, the mountainous elevations which have been formed along the Atlantic coast appear to have been the result of stresses which have acted in a somewhat continuous manner from the Cambrian to near the present day. The dislocations seem to have occurred in these basins as early as the first-named time, and in the basin of Marthas Vineyard they operated perhaps until the first stages of the last Glacial epoch. It is true that the evidence as to the distinct basin-like position in which the rocks of Marthas Vineyard lie is not very clear, for the reason that the eastern wall, if such wall existed, is now below the level of the sea; but the mountain-building nature of the disturbances appears to be unquestionable, the original folds having had a geological height of several hundred feet, though, owing to the soft nature of the strata. they have now been reduced to near their base-levels.

It is a notable fact that in these erosion-basin mountains of the Atlantic coast there is a manifest tendency of the streams to return again and again to somewhere near the paths from which they have been displaced by the subsidence of the areas beneath the sea or by the corrugation of the beds which were formed during these periods of depression. Thus in the case of the basins along the coast of Maine, those of Boston, the Connecticut, and the set about the Chesapeake, streams answering to the original agents of erosion now occupy their ancient sites. It is evident that in this particular, as in many other features, the dislocation areas we are consider-

ing differ from those of normal mountains. In the last-named group, as has been often remarked, the streams very generally come to occupy the geological highlands—the crests of the anticlines. The reason of the departure from the general rule in these antecedent basin mountains is that in them the rim is of hard rock, while the central portion of the area contains softer materials.

It should furthermore be noted that the downsinkings which lowered these valleys, and thus afforded the opportunity for deposition, were not generally so extensive as to induce the formation of normal marine deposits. After the beginning of the Carboniferous, indeed, it may be doubted whether the submergence beneath the level of the sea was, until Cretaceous times, ever great enough to mantle far over the surface of the country. Apart from the local downsinkings, I see no reason to believe that the shore within this time has swayed downward or upward more than a few hundred feet.

So far as the examination has been carried, the seat of origin of the detrital materials contained in the Narragansett Basin is tolerably well explained. The granitic, trappean, schistose, and other rocks represented in the conglomerates, with a single exception, may be paralleled from deposits the like of which are known within a few miles of the margin of the basin. The exception—a most notable one—is in the case of certain quartzite pebbles, sometimes containing an abundance of ill-preserved brachiopods. These quartzites are all fine grained, hardened, but not greatly metamorphosed, and of a hue varying from blue to white. The age of the material, as determined by Walcott, is that of the Potsdam sandstone.

Pebbles of these quartzites plentifully occur in the upper conglomerates of the Narragansett series, as is elsewhere noted in this memoir. They are, however, best known from their occurrence in the drift deposits, where their presence is doubtless to be explained by the breaking up of the Carboniferous beds in which they formerly lay. On the northern shore of Marthas Vineyard they can readily be gathered to the number of many thousands, and on Cape Cod they occur less plentifully as far east as Highland Light.

As the pebbles, so far as observed, are always small, never exceeding about a foot in diameter, and as they are always rounded in a subspherical form, it seems clear that none of them have been brought into

their present position from the original strata by the action of the last ice period. Forming, as they do, a considerable part of the mass of conglomerates in the Narragansett Basin, it is clear that they were derived from an extensive field. Their condition indicates that they were imported from that field by torrent action. Although it is possible that these quartzite deposits originally lay over the country to the westward of the Narragansett Basin, the failure of the beds to appear round the periphery of that area leads to the supposition that the district whence they were derived lay to the eastward of the trough, perhaps beneath the region now covered by the sea This supposition receives some warrant from the fact that these pebbles are most abundant in the eastern portion of the basin, while they seem to be almost lacking in the western part. The existence of these pebbles well toward the extremity of Cape Cod appears to indicate the occurrence of similar deposits beneath the waters of Massachusetts Bay. For further details concerning the origin of these quartzite pebbles, see Part II, by Mr. Woodworth.

AGE OF THE CARBONIFEROUS ROCKS OF THE BASIN.

The evidence goes to show that from the earliest stages of the Paleozoic to the beginning of the era when the Carboniferous beds of this district began to be laid down the field was mainly, if not altogether, the seat of erosive actions. No remnants of the formations between the lower Cambrian and the Carboniferous have been found in folds which exist in the basement rocks of this part of the country. The fact that beds of Cambrian age have survived at several points in the Narragansett Basin in the region to the northward, while no deposits of the Silurian or Devonian horizons have been identified, leads to the supposition that the sediment-making conditions were not in existence at the time these beds might have been laid down. The researches of Lesquereux, a digest of which is given by Woodworth in Part II, make it eminently probable that the Carboniferous series of this field does not begin with the lower portion of the Coal Measures, but with the upper part of that section. Not only are the lower limestones and the Millstone grit lacking, but about half of the measures which normally contain a better coal in the district west of the central Appalachian axis are also lacking.

It should be observed that the fossils which afforded the basis for

Lesquereux's conclusions were obtained from beds which lie at 2,000 to 3,000 feet above the base of the Coal Measures as found in this basin, and that the beds whence his fossils were obtained do not extend nearer than 2,000 to 4,000 feet to the top of the highest remaining beds of Carboniferous age which are found in this area. It is of course possible that the lower portions of the section, the fossils of which have not yet been studied, may prove to belong to the lower Coal Measures, but the essential lithological similarity of the beds below the upper conglomerates makes this view improbable. So, too, the lack of paleontological evidence concerning the precise age of the upper conglomerates permits the supposition that they may belong to the Permian period.

ORIGINAL RELATION OF THE NARRAGANSETT BASIN TO THE SEA.

It is noteworthy that no trace of marine fossils has been found in any portion of the Carboniferous section in this basin. Moreover, there are no limestone pebbles which would lead to the suspicion that beds of this origin had ever formed a part of the original sections. A few limy deposits which occur in the northwest portion of the area appear to be the results of infiltration, and to be classable as veins. When we consider that the Carboniferous section of the West Appalachians exhibits evidence of frequent intrusions of the sea, the question arises how a basin having the stratigraphical profundity of that of Narragansett Bay could have been developed adjacent to the shore line without having, in its repeated subsidences, experienced marine invasion. At the present time the bottom of this basin lies several thousand feet below the plane of the ocean waters which penetrate it. Even before the mountain-building movements which have deformed the rocks began, it is probable that the basin had something like its present depth.

The conditions of the basin, as above noted, lead to the conclusion that during the Carboniferous period it was continuously separated from the sea, and therefore had the character of a lake, or perhaps that of a broad river valley. As it was evidently the seat of very considerable drainage, the outgoing water might have excluded, in a sufficiently effective way, the penetration of the oceanic waters, even though the plane of deposition was not much above the marine level. When, however, we consider how subject all coast lines appear always to have been to oscillations of level, it seems most reasonable to suppose that the basin lay always at a considerable

height above the coast line, and most likely at some distance inland from it. These considerations serve to support the hypothesis, which is suggested by many other features of the Atlantic shore line of North America, that the shore line in later Paleozoic time lay farther east than it does at present.

ORIGINAL DISTRIBUTION OF THE EAST APPALACHIAN COAL FIELD.

The distribution of the Carboniferous strata with reference to the main axis of the Appalachian system affords some valuable information as to the movements and attitudes of the continent during the later stages of Paleozoic and the earlier stages of Mesozoic time. It is noteworthy that, while the Carboniferous of the West Appalachians extends to the southward until the beds pass beneath the Cretaceous and Tertiary deposits which lie to the north of the Gulf of Mexico, rocks of that age are wanting along the Atlantic coast until we attain the latitude of northern Connecticut and southern Massachusetts. Thence to northern Newfoundland accumulations of this age occur, though in detached basins which were evidently formed as somewhat separate areas. The uniform absence of Carboniferous deposits, and indeed of the Paleozoic beds above the Silurian horizon, along the southern portion of the Atlantic coast line of the United States, clearly indicates the long continuance of this part of the continent in the emerged state, a state which appears to have continued in the southern section to Triassic time, and perhaps to the Newark division of that age. If Coal Measures strata had been deposited on this part of the Atlantic coast above the present sea level, it is hardly to be believed that considerable remnants would not have remained in the Dan River, Richmond, and other basins. The natural conclusion is that these beds were not laid down, but that the shore from the Hudson southward remained in the elevated state, and that in this field Carboniferous strata were not accumulated, while farther north the conditions so favored this work of deposition within the region about the mouth of the St. Lawrence that the sections of this stratigraphical division are on the average thicker than they are in the West Appalachian field.

With the advent of the Triassic epoch the whole coast line appears to have been lowered, so that the beds of this age probably formed a more or less continuous sheet from South Carolina to Nova Scotia.

In the Carboniferous downsinking of the eastern shore the conditions which brought about the formation of the Coal Measures do not seem to have extended as far south as the valley of the Connecticut. The pre-

sumption that this trough is old, and that in the Carboniferous period, if it had been sufficiently low lying, it would have afforded a favorable field for the accumulation of strata, is supported by the fact that Helderberg strata are found within its bounds, and the absence of the later Paleozoic is fair proof that the trough was so placed that it remained subjected to erosion. In this connection it is interesting to note that the Triassic period does not appear to have introduced true marine conditions along this coast line. The fossils indicate that the beds were formed either in fresh-water lakes or in estuaries. So, too, the Carboniferous strata of the East Appalachian district contain only fresh-water fossils, notably lacking the thin beds containing marine fossils which in the West Appalachian district clearly indicate successive invasions of the sea. These facts are best explicable on the supposition that the Atlantic coast in this part of its history lay farther to the east than it does at present, and that all the beds from the beginning of the Carboniferous upward through the greater portion of the Triassic section were formed in basins so far separated from the sea that no marine life found access to them.

The development of fresh-water basins on the Atlantic coast in the Carboniferous period has perhaps its parallel on a larger scale in that curious formation of shallow lakes which occurred in Cretaceous time along the eastern border of the Cordilleras of North America, and which gave during the Mesozoic and a part of Tertiary time the nearly continuous fresh-water areas from Texas to the high North. Depressions of this nature appear to be of common occurrence along the bases of mountain ranges which have recently been subjected to extensive movements. It seems possible, indeed, that they are due to counterthrust action, which tends to bear down the part of the earth immediately outside of the field of considerable elevation. Phenomena of this sort are traceable not only in this country, but around the margin of the Alps and other mountain districts which have been sufficiently well mapped to give indications of these old basins. On this supposition we can account for the general tendency of the East Appalachian district to subside during the time when the neighboring ranges were undergoing elevation. The intensification of this subsidence at particular points and the consequent infolding of strata, which have thus been preserved from erosion, is to be explained through the accumulation of thick deposits of unconsolidated rocks in preexisting erosion troughs.

ANCIENT MARGIN OF THE BASIN.

The original extension of the Carboniferous beds the remains of which are found in the Narragansett Basin can not be determined. The evidence goes to show that in the process of filling the trough the margin of the field in which the deposits were accumulated extended in a somewhat continuous manner in every direction, this extension being in a way coincident with the progressive subsidence of the area. There must thus have been a succession of shore lines, each lying farther away from what is now the central portion of the field. It is probable that the arkose deposits which are now found around a large part of the margin of the existing Carboniferous area were accumulated at no great distance from what was the shore line at the time they were formed; but the later shore, answering in age to the upper conglomerate, may have been some scores of miles beyond the present limits of the Carboniferous rocks, the materials being brought in over the shelf of earlier-formed deposits. The fact before adverted to, that the fossil-bearing quartzite pebbles come from some unknown and possibly rather remote district, indicates the validity of this hypothesis.

Although the Carboniferous section of this basin is thick, the fact that the conditions favored the formation of rapidly accumulating conglomerates of itself suggests that some portion of the section has been worn away The fact that no higher-lying beds than the Carboniferous exist in this portion of New England, although there is abundant evidence that a large amount of erosion has taken place since the time of the Coal Measures, is also evidence that a considerable thickness of stratified rocks must have disappeared from this field. The margin of these vanished formations must have been far beyond the limits of the Narragansett Basin.

RELATIVE EROSION OF EAST AND WEST APPALACHIANS.

It requires but a glance at the topography of the districts lying to the east and to the west of the ancient or mid-Appalachian field to show the observer that there has been a great difference in their erosional history. On the west we find the mountain folds on the whole well preserved as regards both their anticlinal and their synclinal elements, the average preservation of the structural features being more perfect than that of any other equally well-known great mountains, except, it may be, portions of

the Jura. In most cases the crests of the anticlines have been widely opened by erosive processes, and in some rare instances the destruction has advanced so far that the synclinal element in the foldings has come to lie farther above the neighboring drainage than the existing crests of the upfolds. Notwithstanding this excessive local downwearing which has here and there taken place, the West Appalachians have everywhere, except in their extreme southern part, retained a striking topographical relief. It is indeed easy to see, even in the most ruined part of these great geological edifices, the plan of the structure and the general features of their architecture. It is quite otherwise with the related elevations of the Atlantic coast. As before noted, the East Appalachians have, in their topographical expression, scarcely a semblance of the structure of the West Appalachians. In fact, their lack of relief has to this day hidden from geologists their real importance as orogenic phenomena.

Between Georgia and the Bay of Fundy none of these mountains have any distinct topographical relief. Here and there the crystalline rock which were formed under their anticlines, or the massive outbreaks of igneous rocks which took place during the folding, remain as considerable hills, or in the case of the Mount Desert elevations they may attain the height of 1,000 feet or more; but in the Narragansett Basin, although the folds certainly have a geological relief of not less than 10,000 feet, the actual differences in altitude from the depth of the present water channels to the highest elevations does not exceed 500 feet. If these mountains of the East Appalachians had been no more worn down than the Alleghenies, they would afford the most majestic elevations in the eastern part of the continent, instead of having no distinct value in respect of topographical relief.

It might at first be supposed that the age of these eastern reliefs is greater than that of the western dislocations; the evidence, however, points to the conclusion that, while some part of the dislocations may be due to stresses which were of Cambrian or Silurian age, the greater of these accidents date from post-Carboniferous times, and are probably to be assigned to the age of the Trias or the Jura. The disturbances which have contorted the Cretaceous or Tertiary rocks of Marthas Vineyard clearly indicate that the orogenic forces have acted along the Atlantic coast with much energy down to very modern time. To what, then, can we attribute the very great differences in the relief of these two mountain-built districts?

The modern school of topographical geologists is disposed to explain such differences as those which we are considering by the supposition that the region of less relief—the eastern—has been long base-leveled, without the refreshment of its relief which is induced by a subsequent process of reelevation; while the western district, having been once, or perhaps more than once, worn down to near the ultimate erosion plane, was lifted again to a height which permitted the machinery of its torrents to sculpture new reliefs. In favor of this supposition there is the fact that the summit levels of many peaks in the West Appalachians are so nearly in one plane that it is not unreasonable to suppose, as a working hypothesis, that the valleys have worn down from an ancient base-level. To this suggestion it may be answered that, so far as the evidence goes, there is reason to believe that the eastern shore has shared in these upward movements. The Berkshire Hills show, by the coincident levels of their summits, as distinct a trace of base-level as do the Alleghenies. Moreover, in the immediate vicinity of the Narragansett Basin the broad ridges of the Worcester axis carry its levels to about 1,000 feet. Yet it is plain that this set of folds owes its origin to the same movements that developed those of the Bay district. In a word, even if we allow that uplift after base-leveling in the one case and lack of the upward movement in the other might account for the very great difference in conditions, we have not the means to verify the hypothesis; it therefore has no apparent value to us in interpreting this field.

Although I regard the considerations which are commonly included under the title of "base-leveling" as one of the most important contributions to physiographical geology, it seems to me that we must guard against the danger of inferring too much concerning the existence of ancient leveling of the land down to near the plane of the sea from the seeming accords in the altitudes of mountain summits. It is easy to see that this accord is only of a very general nature, it being necessary in the classification to allow a range of elevation amounting to several hundred feet. It may well be that, beginning with the utmost diversity which could have existed in the heights of the Alleghenies, the process of downwearing might have brought about as near an approach to uniformity of height as actually exists in the peaks of that range. So long as the rocks are of like hardness and the folds of like size, the tendency would be to keep the downwearing crests at somewhere near the same level.

Another reason for the disappearance of the topographical relief of the East Appalachians can be found in the marine erosion to which they have been subjected. As before remarked, it is evident that the Atlantic coast of this continent has for a very long time been in about its present relations to the sea. It is characteristically an old shore, and has the marks of age in the broad continental shelf which fringes it on the east and in the wide belt of lowlands which lies to the landward of the coast line. These two features seem to be closely related to each other; the submarine shelf probably represents in good part the accumulations of débris which has been worn from the bench which the sea has cut into the land.

Because it is covered by the sea, we can determine but little of the continental shelf, except by inference from what we reasonably take to be an emerged part of its mass as it appears in the structure of the great southern coastal plain, that plain land being evidently composed of continental waste in part removed by marine action, together with the débris of organic forms; but of the bench we may know much, for the greater part of it is above the sea level. If the student would appreciate the importance of this seaboard bench on the Atlantic coast of the United States, he should study the section from the great Appalachian Valley to the sea. Probably the most instructive section is from the region of the upper Shenandoah to the region about Fort Monroe, in Virginia. It is readily noted that the crystalline rocks on the western side of the Blue Ridge rise steeply from the broad vale which is occupied by the Cambrian beds. On this side of the ridge there is no trace of benching; the mountain sides show the ordinary torrent slopes. On the eastern side of the ridge, however, there lies the extensive rolling country commonly known as the "Piedmont Plateau," which has been recognized as a peculiar feature in the section from New Jersey to Georgia ever since the country was occupied by the Europeans. This region has peculiarities of soil and of surface aspect which are due to the fact that it is to a great extent underlain by crystalline or metamorphosed rocks essentially like the complex which makes the higher country of the Blue Ridge. When the rocks exhibit bedding, the attitudes of the strata indicate highly compressed mountain folds. The topography of the district shows much torrent cutting on the surface of a sloping bench which declined toward the sea at the rate of 10 or 20 feet to the mile, the upper or northern margin of this bench passing rather suddenly into the steep slopes of the mountain ranges.

The conditions of the surface are in the main as shown in Pl. I, with the exception that occasional outliers of high land are found over the Piedmont district. These outliers have the general aspect of ancient islands, the bases of which have of late been elevated above the sea level.

Perhaps the best instance of these structures is afforded by King Mountain, North Carolina, which, as has recently been shown by the studies of Prof. Collier Cobb, of the University of North Carolina, is an insular mass which has by elevation been embodied in the area of the emerged continent.

It should be said that this bench, with local variations, extends along the Atlantic coast of the continent as far north as the St. Lawrence district, but that the ancient islands are nowhere so well shown as in the Carolinian section.

The foregoing statements will make plain the working hypothesis as to the erosion of the East Appalachian reliefs. We see that these mountains lie in the realm of the marine bench, that border land of the continent, where the repeated up and down goings of the sea bring the machinery of the surf and the other erosive agents of the coast line—the frost, the tides, and the winds—to bear in succession on every part of the surface. In recent years there has been a disposition to deny to marine action any considerable effect on the topography of a country. This limited view is a natural recoil from the old notion that the sea is the principal agent in land carving. From overestimating the value of a natural agent, the inevitable step is toward an underreckoning, which seems in this case to have gone altogether too far. A part of the misestimation as to the erosional value of the shore agents is due to the study of coastal processes in what we may term adjusted shore lines, such as are to be found where the sea has acted for a long time on a coast where the lands have not altered in their position with reference to the sea. In such conditions the sea, by a complicated system of actions, builds a series of obstructions in the way of shallows and beaches, which serve to bar the land from its assault, and which often cause the energy of the waves and tide to be expended in such wise as little if at all to erode the land. Wherever we are able to study the action of the sea where the land is rapidly oscillating, we note at once the great increase in the effectiveness of the ocean's work. Thus, on the coast of

New Jersey, where the subsidence is at the rate of perhaps 2 feet in a century, the formation of the usual sand barrier beaches is prevented for a considerable section, with the result that the sea, save for the interference of man, works back into the cliffs at the rate of several feet in a year.

While a process of subsidence is in general favorable to marine erosion, that of elevation is probably yet more advantageous to the wave and current work; and this for the following reasons. When the land sinks, the débris due to the surf remains in the possession of the sea and may be used to build barrier beaches at a higher level. Off the coast of North Carolina, where there is also a subsidence movement, because the amount of sand is large, the beaches are still effective walls against the sea. When the land rises, however, the beach material is constantly left behind in the elevated coast lines, and at each successive zone of attack the sea assails an unmasked shore. At present we appear to be in a period where the land oscillations are relatively very slight; we therefore are in a position where we would naturally underestimate the true measure of marine erosion. Still, taken in a large way, we can easily see that the coastal erosion is by far the most effective at the times, which we know to be frequent, when the shore is moving upward or downward. This shoreward-sloping bench may be taken as the result of the two main varieties of land wearing—that due to the natural work of the rainfall, and that due mainly to the stroke of the waves as they break upon the coast. In the equation which determines the slope of the coastal bench, we have to reckon the effect of many agents and conditions. Among these, the successive changes of the base-level—i. e., the plane of the sea—are obviously of great importance. As the surface of the bench gains in height, the capacity of the marine agents become relatively diminished, for the reason that the marine cliff grows higher and the waves have more deportation to effect for each unit of the extension of the scarf into the land. On the other hand, with the gain in height there comes a proportional gain in the wearing power of the rain water, the capacity of which to do wearing work is directly related to the height above the sea at which it comes upon the land.

Although the conditions which are now found on the Atlantic coast of the country are clearly less favorable to erosion than the average, it is evident to the attentive observer that the amount of marine erosion which is now done along the coast from Cape Hatteras to Canada equals if it

does not exceed in volume that which is accomplished by all the rivers which empty into the sea along this part of the shore. We may say, indeed, that the evidence, when fairly considered, leads us to the conclusion that the destruction of the reliefs in the Atlantic coast mountains—the East Appalachians, as we have termed them—has been in a large measure due to the long-continued action of the sea on the zone in which they lie.

In the case of the Narragansett Basin it seems impossible to account for the destruction of the original reliefs by the action of water on its way to the sea. If we take account of the existing water-filled troughs, the arms of the sea, and the rivers, we find a plain cut by relatively wide and shallow canyons, which are now to a great extent filled with drift. This plain is underlain by rocks of very diverse hardness, so that if its surface were due to the result of the downwearing action of streams it should be most irregularly carved, in place of having that shorn-off aspect which the horizontally delivered stroke of the waves produces. Therefore we may conclude that the difference between the reliefs of the East and the West Appalachians requires us to consider the benching action of the sea along with the base-leveling process effected by rivers. Undoubtedly this latter base-leveling action has to be reckoned, but only as one, possibly the least, important element in the action. It may be noted, in order to complete this interesting story, that the greater part of the West Appalachians was fully protected against the action of the Atlantic by the rampart of the Blue Ridge. It is a corroboration of the hypothesis that at the southern end of the West Appalachians, where these mountains were exposed to the action of the waves of the Gulf of Mexico probably at least until the end of the Cretaceous or the middle of the Tertiary period, the mountains show a measure of erosive action hardly less than that which is exhibited by the worn-down ridges of the Atlantic seaboard

Some further consideration of the question as to the wearing down of the rocks of this basin will be found in the next chapter, on the glacial history of the field.

RECENT CHANGES OF LEVEL.

It may be well in this connection to note the facts concerning the recent changes of level in the Narragansett Basin. As elsewhere remarked, the evidence goes to show that the amount of glacial wearing, or at least

that of the last ice epoch, on this field was limited. We may therefore assume, what is inferred from other evidence, that the drainage of the district is substantially the same as it was before the last advent of the glaciers. The drainage consists of sundry deep channels, the arms of Narragansett Bay and their continuations in the narrowed rivers. To explain these stream beds, we must assume that the surface of the country was considerably higher during the preglacial time than it is at the present day. If, as is probably the case, the central part of the bottom of Narragansett Bay is filled in with mud to the depth of 100 feet or more, as is the case with other channels of like character on this part of the coast, then the recent subsidence may exceed 300 feet. A like process of reasoning applied to other parts of the shore between the Delaware and the St. Lawrence leads to approximately the same conclusion as to the amount in which the sea has gained on the land. It should be said, however, that this change in the position of the shore may be due to an alteration in the level of the sea itself quite as well as to the lowering of the land in this part of the shore; in fact, the extent of this modern invasion of the land by the sea along nearly all the shores of the continents raises the presumption that the action may have been due to a vast movement of the floor in some part of the ocean realm.

GENERAL STATEMENT CONCERNING BASE-LEVELING.

What has been said in the preceding pages concerning the relations of marine and land denudation makes it desirable to assemble the considerations which bear upon this problem.

There can be no question as to the importance of the base-leveling theory, which assigns to the atmospheric agents of erosion the downwearing of the land masses. It should be noted, however, that the marine agents—the cutting action of the waves and the marine currents dependent on wind and tidal work—have in their appropriate place a certain amount of influence. It should also be noted that as the land is worn down toward the level of the sea the efficiency of the atmospheric forces in the work of further reduction continually diminishes, because of the lessened fall of the streams and from the tendency of the surface to become deeply covered with a protecting detrital envelope.

In the low levels of the land, where the aerial agents become less

effective, we may always expect to find some effect arising from the repeated visitations of the sea brought about by the almost continual oscillations in the height of the land. The measure of this marine work is commonly the greater the nearer we attain to the average level about which the sea has oscillated for a considerable time. Thus marine action comes in to supplement that of the atmosphere.

Along the coast of New England, and particularly in the district considered in this report, within the limits of the recent oscillations of marine level, we find at many points evidence that the sea at higher stations than now worked to remove the coating of detritus and to expose large areas of the surface to the process of decay, which rapidly tends to break up the rocks. This part of the marine work, in favoring erosion, is perhaps of as much consequence as that due to the direct cutting action of the sea.

It may be remarked that the frequent invasions of the sea, by producing plains of detrital material, such as those which exist in the southern part of the United States, tend also to reduce the surface of the land to an approximately level form. Thus the evidence goes to show that beneath the southern plain the contour of the ancient rocks is irregular, they having been mantled over by a thick coating of débris accumulated along the continental shelf. We therefore see that the ocean tends in two diverse ways to bring about coastal plains—first, by aiding in wearing down originally irregular surfaces to a level attitude; and secondly, by constructing detrital plains over those surfaces which in part have thus been brought to a nearly horizontal attitude.

As for the oscillations of the land which serve to bring the mill of the surf at various levels over its surface, it may be said that since the Carboniferous period there is evidence of many such swingings, which have brought the plane of the sea from a few score to several hundred feet above its present position on the Atlantic base of the continent. The evidence to the same effect from other regions is so extensive that it may be called a world-wide phenomenon. It may safely be assumed that coast lines are normally instable, and this through a range of several hundred feet.

As to the amount of cutting which can be effected by the sea in proportion to that which may be accomplished by the descent of waters from a high level to the shore line, the facts are not yet sufficiently ascertained to permit any definite statement. It may be said, however, that where the exposure is such that the waves may assault the shore with considerable

energy, especially where the tides are high, the erosion, even in a brief period of geological time, is often very great. Thus on the coast of Yorkshire, north and south of Whitby, the marine cliffs, apparently formed in the brief period during which the sea along that coast has had its present attitude, have an average height of several hundred feet, and the platform which marks the lower range of wave action extends on the average a mile or more from the shore. The prism of rock removed by this cutting is in mass greater than we can well assume to have been eroded from the land during the same period for the distance of 20 or 30 miles from the coast line. Along the shore of New England, though the coast generally lies against rocks of more than usual hardness, the benching action of the sea is almost always noticeable. In the few thousand years during which this coast line has remained at its present attitude, the amount of erosion has apparently been many times as great as over any equally extensive interior portion of the field subject to the action of atmospheric agents. Considering only the hard rocks, especially those of the coast of Maine, I am of the opinion that the atmospheric erosion accomplished in New England since the Glacial period has not been so great as that effected along the shore belt in the much shorter time which has elapsed since those coasts began to be assaulted by the sea.

It is to be observed that, in all estimates as to the relative value of marine and atmospheric erosion, account must be taken of the dissolving action of the land waters, which is always wanting in the case of the sea. Although the interior erosion of New England is now exceedingly small, the solutional decay is gradually, indeed it may be said somewhat rapidly, advancing in certain portions of the glacial deposits, so that the time will come when they may pass off with greater rapidity. Making allowance for this and for other evident qualifications as to the relative value of marine and interior erosion, it may still be said that the former agent has a certain and important, though much neglected, influence in determining the shape of the lower-lying portions of the land mass.

CYCLES OF DEPOSITION.

Considerations as to the succession of phenomena of deposition which were brought into view by the writings of the late Prof. John S. Newberry and others, appear to receive no support from the successions of strata in

the Narragansett Basin. The first stage of deposition in this field, when the formation of the Carboniferous section began, is marked by the occurrence of fragmental beds, mainly arkoses. Where the succession is well displayed, these arkoses are followed by conglomerates of no great magnitude. Succeeding these with tolerable uniformity comes a section of several thousand feet where the deposits are prevailingly rather fine grained. In the upper half of the section there is a return to conglomerate-making conditions. This return appears to have been made rather suddenly.

At first sight it seems reasonable to suppose that the succession of events, as indicated in a general way by the section, gave (1) a period in which the shore line was everywhere near to the margin of the present basin, permitting the formation of arkose; (2) a period when a continued depression kept the shore line always at a distance, resulting in the fine-grained beds; and (3) a reelevation, which, by pushing the shores toward the center of the field, led to the ready importation of coarse débris. It is evident that there are many circumstances which serve to qualify the interpretation which can be made as to this and other cycles of deposition. Manifestly the intensity of erosion, as well as of the transportation of detritus worn from the land, depends in large measure upon the ratio of the rainfall at different times. As this ratio doubtless varies in different periods, or even in different parts of the same period, the effect may be to produce great alterations in the character of sediments brought to any particular field. Moreover, along the coast line, when it is in a static condition, there is an obvious tendency to produce a shelf, which, advancing from the shores of the basin, may afford a slope over which, in time, coarse sediments may be transported to a distance from the shore to which they could not at first have attained. On these and other accounts it does not seem profitable to attempt any conclusions based upon the succession of beds in this area.

ARKOSE DEPOSITS OF THE BASIN.

As the interpretation of much of the history of the Narragansett Basin depends on the view that is taken of the arkose deposits which abundantly occur at various points around its margin, and are, indeed, a characteristic feature of that rim, it will be necessary to consider the significance of these accumulations.

Geologists who have had to deal with arkose deposits have generally accepted the conclusion that they indicate the accumulation of detrital

materials derived from crystalline rocks which have been subjected to much decay in place, so that they lost their original cohesion before they were subjected to transportation and were accumulated in their present situations. The essential characteristic of such deposits is that they contain considerable quantities of crystalline materials in which the fragments have not been reduced to sand, but retain, in good part at least, their original form. In other words, the presence of arkose beds means an antecedent decay in crystalline rocks, a decay taking place in such a manner as to loosen the crystals from their attachments without going far enough to disintegrate the bits. This action has been followed by the wearing away of the softened mass and the more or less complete rearrangement of the materials.

In the present state of the study of arkose beds, pains has not been taken to discriminate the materials into the two groups into which they may naturally be divided. In certain cases, after the process of decay has broken up the texture of the crystalline rock, and perhaps removed much of its materials in the state of solution, the deposit remains essentially in its original place, where it may be covered by subsequently accumulated deposits. Even though recementation of the crystals takes place, the accumulation will have more or less of the character to which we gave the name of arkose. For convenience, we may class this group as unremoved arkose.

Although the conditions which favor the formation of unremoved arkoses must be of infrequent occurrence, instances of the kind are to be observed in certain parts of New England, where the preglacial decay reduced considerable quantities of the crystalline rocks to a disintegrated state, and where the beds thus softened were not removed by the glacial wearing, but remain to the present day covered by sheets of stratified or unstratified drift. The normal or transported arkoses can, in all cases, be discriminated from those which have remained in place, by the evidences of water action afforded by more or less obvious stratification.

The most characteristic and readily interpretable deposits of arkose exhibited within the limits of the Narragansett Basin, indeed one of the most important accumulations of this nature ever described, occurs at Steep Brook, the station just north of Fall River, Massachusetts. At this point, lying against the granitic rocks which form the western margin of the basin,

is a section of what at first sight appears to be a mass of granite which has decayed in place. This seemed to be the view which was enforced by the observed facts when these beds were first seen by me, about twenty-five years ago, and they had just been opened by prospectors who were led by a small outcrop on the brook to seek for fire clays. Further exploration, however, soon disclosed the fact that the mass exhibited traces of stratification such as were not to be found in the neighboring unchanged granite. A close study of the obscure divisional plane brought to light the existence in them of many well-preserved specimens of plants which belong to the Carboniferous time. This evidence indicates that the deposit was formed during the period of the Coal Measures. The considerable thickness of this section makes it clear that the conditions which led to its formation continued for a long time. These conditions were substantially as follows: There was a rapid importation of semidecayed granitic rock, such as would be afforded by the decomposition of the crystalline materials which are to be found immediately to the east of the locality. The rate of this accumulation appears to have been so speedy that there was no chance for a true soil layer to be formed on the growing beds. The plant remains which occur were evidently not grown on the sites they now occupy, but were fragments swept into their positions from a distance. It appears likely that they had been to a greater or less degree inclosed in ordinary ferruginous concretions before this transportation.

The interpretation of the conditions at Steep Brook during the time when the forces which led to the deposition of the arkose were in action seems, in a general way at least, to be not at all difficult. It is evident that in the time preceding the deposition of the portion of the Carboniferous strata on which the arkoses lie, the portion of the continent about the Narragansett Basin had been long exposed to atmospheric decay without having been subjected to the conditions which would remove the decomposed material as rapidly as it was brought into the disintegrated form. Judging by the conditions which have affected the fields that now afford or that might produce the arkose deposits, we may assume that these levels of the Coal Measures time had long been the seat of a considerable rainfall and had maintained a coating of vegetation, such being the antecedent conditions of any decomposition which would prepare the way for arkoses. After the development of a sufficient depth of this rock decay, we have to

suppose that conditions favoring the rapid erosion of the decayed material were established. These conditions may have been brought about in any one of several ways: The region may have been subjected to glacial action; the rainfall of the area may have been increased in such a measure that the streams were made competent to waste the surface; or the area may have been exposed to wave action, either by being lowered beneath the level of the sea or by becoming the seat of a lake.

The hypothesis of glacial action at the time these arkoses were formed does not, at first sight, seem to be supported by the evidence which is derived from the presence of well-preserved vegetable remains in the beds; but, as remarked in the preceding paragraph, these remains seem not to have been deposited in a fresh state in the growing accumulation, but to have been washed from some antecedently formed but practically contemporaneous deposit into the positions which they now occupy. Therefore the existence of ice wearing in this district at the arkose-building time does not seem improbable. We shall hereafter note that there is other evidence of a more positive nature going to show the existence of glacial conditions in this gravel period in the district about the Narragansett Basin.

As a whole, the distribution of the arkose deposits of the Carboniferous time around the margins of the Narragansett Basin seems most easily to be explained by the supposition that streams of a swiftly flowing nature formed torrent cones when they debouched into a fresh-water lake which occupied almost the whole area now covered by the coal-bearing rocks of the district. That the deposits are in general those of torrent cones or deltas appears to be shown by their irregular distribution. In all cases where they have been observed they occur in rather detached patches, like accumulations which have no great extension in the direction of the ancient shore line. This seems to exclude the supposition that the deposits were formed in the manner of ordinary shore accumulations, where the débris is transported from a neighboring coast escarpment.

There are no observations on record concerning arkoses now in process of formation, though such may be accumulating in many parts of the world. It is therefore not possible to ascertain with certainty the distance to which the angular crystalline débris of granitic rocks can be conveyed by stream action without losing the peculiar features which separate it from the ordinary products of the erosive forces which have acted on much

decayed rocks. It happens that on the island of Marthas Vineyard there are extensive deposits of arkose formed during the Tertiary period, which appears to indicate that materials of this nature may be transported for considerable distances. The deposits at Gay Head contain very thick beds of arkose, probably brought from the granitic area lying to the northwest of the locality. It is difficult to conceive that the supply of the detritus could have been brought from less than two score miles away from the locality in question. It is of course possible that these Tertiary arkoses were derived from some granitic area near the place where they lie—an area which by local subsidence or excessive erosion has in modern times been brought below the level of the sea; but the evidence in these cases is clearly against this hypothesis and in favor of the assumption that the little-rounded crystals from the granitic sources have been conveyed for forty or more miles. Therefore, while the Carboniferous arkoses afford clear evidence that they were deposited along the shores of a basin, no very clear evidence as to the field of their derivation can be obtained from the conditions of the beds.

The arkose deposits of the Narragansett Basin are found in both groups of deposits which have been observed in the field, the Cambrian and the Carboniferous. In the former the evidence is limited to the region about Attleboro, that being the only portion of the basin where the Cambrian strata are clearly recognizable. The Carboniferous arkoses are much more extensively distributed. They may indeed be said to occur as a characteristic feature in the margin of the basin, serving to show that, in a general way at least, the trough existed with something like its present horizontal limits as early as the time of the Coal Measures. At no other point are the evidences as to the conditions under which the deposits were laid down so clear, or at least so well ascertained, as at Steep Brook, but at all points the facts show that the materials composing the beds have been transported from a distance, and so far as determined the carriage has been from the sides of the basin toward its central part.

It is important to note that the arkose deposits of this district appear to have been the first of a series of erosional phenomena leading in the end to the formation of extensive conglomerates. The stages are, first, the arkose material, or the waste of rocks decayed in place; next, the clays and sands, which may be regarded as the product of ordinary erosion, when

the abrasive forces keep pace with the agents of decay; and finally, the conglomerates, formed when the abrasive actions go forward more rapidly than those which lead to the general softening of the rocks.

RELATION OF ARKOSES TO EROSION.

The above-mentioned facts concerning the succession of beds in the Narragansett Basin clearly point to the existence of what may be termed a cycle of erosion dependent on the relative rate at which the two diverse processes connected with the decay of the lands go forward. This equation, in a general way, seems to be as follows: Where the rainfall is so slight that a vegetal covering is not established in a country, the chemical assault on the rocks, which is due in the main to the CO_2 and other products which the decaying organic matter in the soil contributes to the ground water, is probably wanting. The result is that the erosive work, or that which operates to remove the detritus in the form of visible sediment, though it may be very slight, is likely to be enough to keep the rocks which have been softened well cleared away. In such an arid country the rainfall is apt to be irregularly distributed, so that the torrent action is at times exceedingly strong. The result of this is that the valleys become encumbered with angular breccia-like débris, such as now exists in the valleys of the arid districts of the Cordilleras.

An increase in the rainfall to the point where an ample mantle of vegetation is supplied, but short of the point where torrent action is made excessive, tends to produce a greater amount of decayed rock than can be cleared away. The result is that the coating of what we may term the the nontransported arkose steadily increases in amount. The thicker this porous layer becomes the more the rate of the torrent action approaches uniformity, for the reason that the open structure of the decayed rock causes the corroded zone to be an effective storehouse for the ground water, whence it is slowly yielded to the streams. With an increase in the rate of precipitation beyond the point where the water can be taken into the unoccupied detrital layer a critical point is soon reached where the mechanical erosion will rapidly increase and will gain on the process of interstitial decay. If the rate of mechanical wear much exceeds that of the decay, the result will be the deportation of solid waste in the form of pebbles, the process being marked in a geological way by the production of conglomerates.

We thus see that in the erosional history of a region wherein the rainfall varies from zero to the highest measure which we can expect, say over 100 inches per annum, we may look for a series of effects which will mark themselves in diverse classes of débris. So long as the decay keeps in general ahead of the abrasional work, the waste which goes forth through the streams is likely to be of a finely divided nature, giving rise to clayey slates as the natural product. If a stream yields abundant materials which would form arkose, it is because the erosion is gaining on the decay. If the work produces pebbles, the indication is that the mechanical erosion is so great that wearing by solution plays no important part in the process.

In this connection it will be well to note yet further that the large production of pebbles within a short time can scarcely be accounted for except on the supposition that the abrasion has been brought about by the action of glacial ice. As the importance of this proposition has not been appreciated by those who have dealt with the problems afforded by conglomerate deposits, we must note that there are but three ways in which waterworn pebbles can be made in sufficient quantities to afford materials for ordinary conglomerates. The first and practically the only effective means by which pebbles can be extensively made—i. e., in large amount per unit of surface over a large area—is by glacial action. Where the precipitation of a country goes off as an ice sheet, every portion of the rocks over which it flows, if the material be sufficiently hard, becomes a part of a vast bowlder factory—for such, in fact, is all the base on which the glacier rests. As the average thickness of the till covering in the glaciated district of this country is not less than 10 feet, and as the greater part of this till is bowlders, it is clear that ice in motion is specially adapted to forming such partly rounded bits of stone. The materials in our eskers show how successful the subglacial torrents, with their currents impelled by hydrostatic pressure, were in completing the rounding of pebbles which the ice began to shape.

When the rainfall of a country goes to the sea in a fluid state, the torrent section of its river system, provided the rate of decay is swift, is likely to be the seat of the production of a considerable amount of pebbly material. Yet the share of the energy of the portion of the rain water which is then effectively applied to pebble making is but a small fraction of what is used when the same amount of precipitation goes to the sea in the form of a glacier. Moreover, the pebbles which are thus formed in ordinary tor-

rents are made in small quantities. No sooner does a torrent bed become loaded with this detritus than it ceases to be an effective factory of the rounded bits of stone. Furthermore, the pebbles which are formed in torrent beds rarely attain the sea or any position where they can be built into extended beds of conglomerate. Although I have inspected several thousand miles of seashore, much of it along mountainous coasts, I have never found a place where pebbles, such as are found in the conglomerates of the Narragansett Basin, from a stream of any size were entering the sea. It may, indeed, be regarded as rare for a stream to discharge into the ocean pebbles exceeding an inch in diameter. To do such work it would have to flow at a torrential rate at its very mouth, a condition which can be found in certain fresh-water lakes, but is rarely seen on the ocean coast line.

The third means of pebble making may be seen along the seashore where the waves are attacking hard rock cliffs. In such conditions pebbles are formed, but they are rarely accumulated in large quantities; in general the fate of coast-made pebbles is to be worn out by the action of the forces which have shaped them. There are no agents whereby such marine pebbles in considerable quantities can be carried out for any distance from the shore. In rare cases ice forming along the coast is likely to inclose some portion of the shore débris; this shore ice may then drift out to sea and there deposit the load of pebbles which it has rafted. This action, though sufficient to strew the sea floor with shore-made stones, can not be looked to as a means of accumulating conglomerates.

The above-mentioned considerations make it clear that it is not easy to account for the existence of widespread deposits of pebbles of considerable size accumulated in massive strata, which in the case of the beds of the Narragansett field contain perhaps more pebbles than exist on the beaches of the Atlantic coast or in all the torrent beds of the Appalachian Mountains. The easiest way, if not indeed the only way, to explain the formation of extensive conglomerates is as follows: On the surface of a land area there must first be accumulated a considerable deposit of rock fragments, such as is normally gathered at the close of a glacial period, or such as occupies a region of high relief, scanty rainfall, and much frost work, after the manner of large areas in the Cordilleras and in other parts of the world where these conditions exist. If, now, such a fragment-strewn district is gradually lowered through the mill of a shore line either of the sea or of a

considerable lake, the chance for the formation of normal conglomerates will be provided. The unorganized débris of the surface will be taken to pieces and recomposed into stratified beds, as is now being done with the glacial débris along the shores about the North Atlantic. In this formative process the pebbles are likely to be changed in shape and assorted as to size in a way which at once distinguishes the strata into which they are built from the beds of till or of residual breccia from which the fragments were derived.

There are certain tests of some value in distinguishing the conglomerates made from rearranged glacial materials from those which owe their formation altogether to marine action. Pebbles made from fragments which have long been separated from the bed rock are generally, unless they be of quartz, much affected by decay; they contrast distinctly with the fresh quality of the ordinary glaciated pebbles. As I have observed in the southern part of this country, as well as in southern Europe, the detrital waste which comes into the streams is generally so penetrated by decay that it can not be made into pebbles; if perchance it holds together in the shaping, the eye at once separates the bit from those which are made from freshly riven stone.

Where pebbles are made by wave action alone, it is a notable fact that they exhibit very little diversity in form; they are almost invariably spheroidal, and when they are accumulated in considerable numbers the lithological diversity of the material is small. Although glaciated pebbles are apt to be somewhat altered from their original subangular shapes as they pass through a surf line, many of them, as we may note along the New England coasts, will withstand a deal of hammering without losing the distinct mark which the ice work impressed upon them. Moreover, taken collectively, whether in the original till or in the partly masked shore deposits, they commonly exhibit a large petrographical range of material. The facts which are available for the interpretation of conglomerates show that those of the Narragansett Basin are of what we may term secondary glacial origin. This is indicated by their frequent—indeed, we may say usual—subangular form, their petrographical variety, and the very small amount of decay which had affected the rock masses after they left their original bedding places and before they were deposited in the situations in which we now find them.

The hypothesis that the conglomerates of the Cambrian and Carboniferous as exhibited in this locality are the results of glacial action is supported by the general distribution of such deposits in this and other countries. Massive conglomerates of great areal extent are distinctly more common in high than in low latitudes. With rare, and in most cases questionable, exceptions the deposits of this nature which can be traced horizontally for a great distance from north to south fade away as they approach the equator. As our study of conglomerates advances, more of the deposits are found to afford evidence as to the glacial origin of their pebbles. The great conglomerates at the base of the Carboniferous in India, which from their interstratified position appeared not to be open to the explanation which has been advanced in this writing, have recently afforded clear evidence to show that glaciation, possibly occurring at a time when the area was elevated to a great height above the sea, sufficiently accounts for the origin of the pebbles and bowlders which the beds contain.

Although this is not the place for an extended discussion of the matter, it may be worth while to remark that a collation of the recent studies on conglomerated deposits clearly shows that we are fast approaching the point where beds of this nature will be taken as presumptive evidence of glacial action occurring at the time of their deposition, or perhaps immediately preceding it.

RECORD VALUE OF CONGLOMERATES.

In connection with these considerations relating to conglomerates, it may be well to note that deposits of this nature have another much neglected element of value to the geologist, in that they afford him an opportunity to ascertain many facts concerning the physical conditions of the region in which they occur at the time of their formation. Although the value of these indications is in good part self-evident, they have been so generally neglected that it is worth while to dwell upon the methods of using them and to illustrate them by a special study of the Narragansett field.

If a conglomerate has not been subjected to metamorphic action sufficient to change the original character of its pebbles, these fragments may be taken as evidence concerning the state of the rocks whence they came at the time the pebbles were brought together. This evidence,

when examined, is seen to go very far, and in several directions. In the first place, the conglomerate may be taken as representing the beds which were exposed to erosion at the time it was formed. If the beds are of ancient and of known age, they may enable us to determine the former existence, in the field, of rocks which have since disappeared by erosion, been lowered beneath the sea level, or been covered over by other deposits. Thus, in the case of the Carboniferous conglomerates of the field under consideration, we find in the beds a very great number of quartzitic pebbles which contain fossils evidently of the Cambrian age. It is clear that the field occupied by the quartzites was extensive, for the fragments which appear to be of that group of rocks, though not always containing fossils, are about the most numerous of the components which make up some of the thickest layers of the Carboniferous conglomerates. A careful search of the rocks of eastern Massachusetts has failed to reveal the source of these fossil-bearing pebbles. Strata perhaps about the same age are found in various parts of eastern Massachusetts, but they are lithologically and in fossil contents very different from the strata which afforded the pebbles. While it is possible that the field whence the quartzite bits came has, by differential warping, been carried beneath the sea, it is rather improbable that such has been the case; it is more likely that the rocks in question lay on the margin of the basin, whence by erosion they have disappeared.

It is a noteworthy fact that the above-mentioned quartzite is the only rock of the many contained in the Carboniferous conglomerates which has disappeared from this part of the country since these beds were formed. There are, it is true, certain uncharacteristic sandstone pebbles which can not clearly be identified with anything now in or about the basin, but these are not numerous. The impression left by the study of the Coal Measures pebbles is that the general character of the rocks exposed at the surface in this field in Carboniferous time was substantially the same as that of the rocks remaining at the present time. This view is justified by a comparison of the materials contained in the ancient and the modern aggregations of glacial waste. Taking pains to exclude from the waste of the last Glacial period the pebbles which have been worn from the basin rocks of this field, the observer is at once struck with the likeness of the two assemblages, a likeness which shows us that the erosive agents found, with the exception of the above-noted quartzites, much the same rocks open to

their assaults in these two periods, which must have been separated by some millions of years.

The field open to examination is much more limited in the case of the Cambrian conglomerates than in that of the Carboniferous pudding stones. Moreover, the pebbles contained in the beds have been subjected to more metamorphism. Nevertheless, the studies which have been made show that the rocks of the fundamental complex had attained about their present constitution before the beginning of the Olenellus epoch. These pebbles represent the granites, gneisses, quartzites, etc., of the rocks which are found beneath the Cambrian beds, and show that the crystalline condition of these deposits was approximately the same as it is now. It is evident, however, that there were quartzites and other semimetamorphosed beds which afforded waste to erosion in the Olenellus epoch, beds which are not recognizable as in place in the district, and which perhaps, like those noted in connection with the Carboniferous, have disappeared from the district. It is nevertheless clear that the greater part of the crystalline rocks of this district were already not only in their present mineralogical condition, acquired during a period when they had been deeply buried beneath other rocks, but had been stripped by the erosive forces of this ancient covering.

It must not be supposed that the whole or even the greater part of the metamorphism which has taken place in this region had been accomplished by Cambrian or even Carboniferous time. While in certain districts and with certain rocks this work seems to have been then completed, or nearly so, in other parts of the field the action continued at least until after the deposition of the Coal Measures strata. Thus the beds of the last-named series in the region about Worcester and in that about Wickford have been transformed to gneisses which, but for collateral evidence, could not be recognized as having been, in their original state, the associates of ordinary coals. It is evident that in this last-named field the process of metamorphism has gone on with exceeding irregularity, certain parts of the most ancient deposits—as, for instance, the fossiliferous strata of the Olenellus horizon—being not much altered beyond the induration common to all ancient flaggy layers, while but a few miles away conglomerates have been so far converted into crystalline rocks that the original character of the beds has been almost completely lost.

RED COLOR OF THE CAMBRIAN AND THE CARBONIFEROUS.

The red hue of certain portions of the Cambrian as well as of the Carboniferous rocks affords a matter for inquiry. Though no solution of the problem has been attained, it may be well to note certain facts of possible value to those who may hereafter attack the question. It is noteworthy that the red beds of both the above-mentioned series occur on the western and northern sides of the Narragansett Basin and in the trough of the Norfolk Basin. In both these sections the red beds are somewhat irregularly distributed, generally occurring between deposits which have no trace of the peculiar hue. In some cases, as noted by Mr. Woodworth, the red stratum may be but a few inches thick, lying between sandstones or arkoses of a whitish hue. This peculiarity of distribution is also very noticeable in deposits exhibited at Gay Head and elsewhere on Marthas Vineyard which, in Cretaceous and Tertiary time, were made under conditions somewhat similar to those which existed in the earlier periods when the Narragansett deposits were formed.

It seems likely that the red hue of stratified deposits is due to a variety of actions. In some instances, as along the present coast line of the region and about the mouth of the St. Lawrence, red beds may be formed by the disintegration of Triassic or other red sandstones and clays, the rearranged material retaining in large measure the hue of the rocks whence the débris came. In other instances, perhaps in the case of the Cambrian and possibly the Carboniferous of the Narragansett field, the red hue may be due to the fact that the beds thus colored originally contained a share of lime carbonate. Downward-percolating waters containing iron oxide transformed these beds first into impure siderite, and further change served to bring the iron into the state of limonite. The coloration thus brought about is frequently to be observed in the Devonian and Silurian rocks of the Appalachian district, being particularly conspicuous in the iron-bearing members of the lower Devonian and upper Silurian strata of eastern Kentucky, as for instance in Bath County. In yet other instances the decay of crystalline rocks containing a considerable share of iron may have provided the ferruginous material in a direct manner in the process of sedimentation. Some unpublished studies as to the amount of magnetic oxide in the drift covering which exists in this part of New England have shown me that the

proportion of this material ranges from about one-half of one per cent to as much as five per cent by weight of the mass. As further oxidation of these crystals of magnetic iron goes on but slowly, the deposits in which they finally come to rest may contain a large share of the material which is to be, by further change, dissolved and distributed through the bed. Even where the ferruginous matter has been accumulated between the fragments of rock in the form of a thin vein or coating separating the bits, it may by a further process of change lose the iron in a greater or less measure and become a mere stain.

CHAPTER III.

GLACIAL HISTORY OF THE NARRAGANSETT BASIN.

The interpretable history of this basin, so far as it has depended on the action of ordinary streams and of the sea, has already been set forth. This account of the effects of the solar energy which has been applied through the atmosphere needs to be supplemented by some consideration of the work which was done during the Glacial periods. The account which will here be given of the work will in the main be restricted to the phenomena that are in some measure peculiar to the field, for the reason that the surface geology of New England is to be the subject of a separate publication by the Geological Survey. Any full discussion of these matters in this memoir would therefore involve an undesirable repetition.

We may first note that the deposits formed during the times represented by the conglomerates of the Carboniferous series have a character which warrants the hypothesis that they are to a considerable extent the products of glacial action. The view that this age was a period of recurrent ice work has already been ably presented by the late Dr. James Croll. Here, as elsewhere along the Appalachian district, the supposition is supported by an array of facts which deserve more attention than they have received. These facts, as they are exhibited in the country from Alabama to the St. Lawrence, will be briefly set forth.

CARBONIFEROUS CONGLOMERATES.

In the Southern States the conglomerates of the Carboniferous periods are, with rare and unimportant exceptions, made up of pebbles of quartz, which, as has been noted by several observers, are evidently the remains of the undecayed veinstones that survived the decay which, in the pre-Carboniferous, as in the modern time, greatly affected the rocks that were exposed to the atmospheric agents. The great thickness of these quartz

conglomerates, their wide distribution, as well as the general absence of fossil remains, are best explained on the supposition that the erosion took place in an ice time, being effected by the glaciers or by the currents of living water which coursed beneath them. In no way save by comparing this ancient work with that now in progress in glaciated regions can we well account for the deposition of the Millstone grit of the Southern Appalachians.

As we go northward from the valley of the Tennessee the Carboniferous strata show an increasing amount of pebbly material which has been derived from the undecayed bed rocks. As elsewhere noted, these rocks indicate that there was at the beginning of the period a considerable thickness of decayed material, but before long the erosive agents had removed this friable mass, and thereafter the supply of pebbly matter, vast in amount, was obtained by the breaking up of bed rocks which show no evidence that they had been affected by superficial decay. As we go yet farther north, in the next field where the rocks of this age appear, i. e., in the region about the south shore of the St. Lawrence, the thickness of the conglomerate even exceeds that of the sections hereafter to be described in the northern part of the Narragansett Basin. In a word, the facts make it evident that the Carboniferous period of the eastern part of North America, like certain other periods, was one of exceedingly rapid alternations between the conditions which favored the development of marsh vegetation and others under which the accumulations of coarse sedimentary deposits went on with great rapidity.

Although there are instances in which a torrent may accumulate a large detrital cone composed of bowlders and pebbles, I know of no geological machinery now at work on the earth's surface, or which can reasonably be supposed to have operated in the past, except glaciation, that is competent to produce such immense masses of coarse detritus as are contained in these conglomerates, or bring them into position where water action can effect their arrangement into beds. The area of the deposits lying on the two sides of the old Appalachian axis probably now exceeds 60,000 square miles; the average thickness of the section is certainly not less than 2,500 feet; so that the amount of matter of a prevailingly coarse nature which was laid down along the old Appalachian ridge in a period apparently of no great duration was not less than 20,000 cubic miles, and probably was

far more than that amount. When we remember that the whole drainage basin of the Mississippi—a region which is probably many times as great as the field whence this detritus came—yields to erosion not more than about a twentieth of a cubic mile each year, it becomes evident that we have to bring into our conception of the causes operating in the olden day some more effective agent of erosion than is found in free water.

If all the detritus of the Carboniferous conglomerates were of the same nature as that which is found in the Southern Millstone grit and the related beds, we could perhaps assume that their production was due to the invasion of the sea acting upon a deep decayed zone, but the fact that the thickest of these deposits occur in the northern part of the Appalachian field and are composed of undecayed pebbles negatives this hypothesis and requires us to assume that the erosion attacked the bed rock with great intensity. That this attack was by torrent action is extremely improbable; for, as before stated, no torrents are now known to produce so large amounts of pebbles of crystalline rocks as were formed at this time; and when such fragments are formed, so far as my observations go, they always present marks of decay, due to the slow manner in which they are shaped and to the conditions of their storage in detrital cones. The pebbles of the Narragansett and other conglomerates of the same age which I have examined, even those of a compound nature, are in practically all cases as fresh as those contained in the bowlder deposits which were formed during the last Glacial period. This appears to negative the supposition that they could have been the result of ordinary torrent action and to require a method of formation which apparently can be explained on the hypothesis of glacial erosion.

It should be noted that the pebbles of the Carboniferous conglomerates, especially in the Narragansett district, show no trace of glacial scratches; moreover, they generally have a rather rounded form and are of less varied size than those in any of the till deposits formed during the last Glacial period. In some cases, however, they seem to me to retain the faceted shape which is so characteristic of ice-made pebbles. When compared with the pebbles of the last Glacial period, which, in a measure, have been subjected to marine or stream action, they are found to correspond with them in all essential features, except when, as is often the case, the old fragments have been deformed by stresses which came upon them since they were

built into the Carboniferous strata. The absence of large bowlders in the Carboniferous is paralleled by what we find in the modern washed drift; there, as might be expected, the larger fragments have been kept out of the beds by the sorting process which takes place in water transportation.

The facts disclosed by a study of the conglomerates of this basin lead to the conclusion that the pebbles were probably formed by glacial action, and that the fragments were brought to their present position by torrents which swept into the basin from the highlands that bordered it. Their transportation to their present sites, as well as their distribution into beds, may have been due to waves and shallow-water currents acting during a period of increasing depression of the land. In no way save by glacial work does it seem to me possible to account for the rapid formation of the great mass of pebbly detritus which is contained in these beds. It therefore may fairly be held that the Carboniferous period, in this district at least, was one of extensive and long-continued glacial action, and that the greater part of the section exhibited in the basin is made up of rocks which owe their more important features to the action of glaciation. From the Carboniferous to the Pleistocene this area affords no evidence of ice action.

LAST GLACIAL PERIOD.

The last Glacial period has left upon this district marks of its action which are as indubitable as any that are found in the region to the northward. In the time of the greatest southward extension the front of the ice evidently lay considerably to the south of the whole southern shore of Massachusetts, Rhode Island, and Connecticut. This is shown by the presence of extensive moraines on the Elizabeth Islands, Marthas Vineyard, and Nantucket, as well as on Long Island, New York. A careful inspection of the marine soundings off this shore has failed to reveal any indications of a submerged moraine marking the extreme line to which the ice sheet attained. Moreover, the evidence gained by the study of the front over the land from the coast of New Jersey to the far West goes to show that the extreme extension of the ice was of a very temporary character, the considerable halts having taken place in the stages of retreat which probably began very shortly after the farthest southward advance had taken place.

The stages of retreat of the glacier in and near the Narragansett Basin are fairly well marked by the occurrence of frontal moraines. These

moraines consist in part of ridges composed of glacial waste, in characteristic, irregular, shoved attitudes, each ridge with a more or less distinct sand plain or frontal apron on the side which lay away from the ice, and in part of bowldery tracts where the glacier did not build a distinct or frontal wall or where it may have overridden or broken down the barrier after its construction. It should be noted that these moraines, unlike those on Long Island and Marthas Vineyard, are not placed at right angles to the general trend of the ice movement, but on the west side of Narragansett Bay are turned into a nearly north-and-south position. Beyond the head of the bay they again turn more nearly to the east-and-west direction. On the eastern side of the basin the ridges are not traceable with sufficient distinctness for mapping, but the outlines of the ice front at the time of the formation of this moraine are well enough shown to make it plain that there was a deep indentation at that point, so that while the ice overlapped the present shore on either side of the basin the front did not extend much south of Taunton. Such lobations of the margin, as they have been termed by Chamberlin, were very common along the front of the great ice field. They are due to irregularities of the surface over which the ice moved or to other local conditions. In other instances the presence of a deep, broad valley, such as is afforded by the channels of the Narragansett Bay, led to the projection of the ice at its mouth beyond the main line of the front. In this instance the retreat of the front was probably due to great volume of the subglacial streams which flowed from the areas to the northward. Their effect on the ice at the margin would be to melt it away at the base, making the formation of icebergs an easy matter. As the region was evidently depressed below its present level at the time the ice was most advanced—lowered, it may be, to some hundreds of feet below its present altitude—the undermining action of the waters would naturally tend to detach bergs.

It is evident that the ice front in the region between the northern part of the basin and the sea was subjected to many alternations of advance and retreat which are not registered in any distinct moraines. About twenty years ago, when the Old Colony Railroad Company was widening its roadbed, the new-made sections distinctly showed that there had been a score of these oscillations in the line from North Easton to Somerset, each marked by the disruption and erosion of the deposits which had previously been

formed at the front of the ice. The same evidence is visible at the present time, though less distinctly, in similar cuttings which are making from Brockton southward. The result of these irregular movements of the ice has been to give the drift deposits of this field a peculiarly irregular and confused character. The greater part of the eskers or ridges of sand, gravel, and bowlders which were formed within the ice-carved channels that were excavated by the subglacial streams has been effaced.

It is a notable fact that in the southern part of the basin, on the shores and islands of that part of it which is included in Rhode Island, eskers are essentially absent, except near the moraine which borders the western margin of the field. This seems to be due, not to the successive advances and recessions of the ice front, but rather to the fact that the very deep channels of the bay provided ample low levels through which the subglacial streams made their way to the sea. In the district between the railway bridge at Somerset and Steep Brook Station there is an extensive and very characteristic area of those "pitted plains" which are often found near where a subglacial stream discharged its current into open water. The area which now remains is evidently only a fragment of the original field. The materials seem to have been brought to their position by an under-ice river which followed in general the line of the present Taunton River. The cause of the pittings is not yet determined, but they are probably due to the embedding of masses of ice in the swiftly accumulating detritus, these small bergs being weighted down to the bottom by the amount of rocky matter which they contained; when they melted, the originally level surface fell into its present shape.

The till or bowlder-clay coating of this district is, on the average, less thick than in the region lying immediately to the northward; wherever the section extends to the bed rock this most general element of the drift—the waste dropped on the rocks in the last retreat of the ice—is commonly found to have a thickness of less than 10 feet. Although this till sheet, when it covers rounded masses of the bed rocks, often takes on a drumlin aspect, it seems clear that there are none of these peculiar lenticular hills in the basin. Their absence on the margin of this part of the continental glacier is in accord with their distribution in other parts of this country; they are evidently due to the conditions which prevailed in the portion of the ice which lay near the margin, but not usually within 50 miles or so of its verge.

It is to be noted that the till materials of this basin contain a much smaller amount of clay than is the case with the like deposits farther inland. This is probably due to the fact that in this marginal district the materials composing the till consist largely of esker and other washed gravels that had already lost their clay element. In the irregular movements of the ice and of the subglacial streams a large part of this clayless matter is brought again into the ice, and in the end finds its way to the surface in the form of till. The result is that in this marginal portion of the glacial field in New England there is often little difference in the materials which go to make up till or kame deposits, the clay element having been in both cases washed away. The effect of this is to make the value of the fields for tillage much less uniform than is the case where the till deserves its ancient name of bowlder clay.

The origin of the glacial detritus of the Narragansett Basin has not yet been fully traced. From the studies which have been made it is sufficiently evident that the carriage in the case of the materials contained in the till has in general been for no great distance. Although, as will hereafter be noted, there is at least one case where the transportation has extended very far, the evidence shows that at least four-fifths of the till débris has been carried not more than 5 or 6 miles. This determination is easily made on the northern border of the basin, where the line between the pre-Cambrian and igneous and the Carboniferous rocks can be traced with approximate accuracy. The materials which have been conveyed in the subglacial streams, here as elsewhere, have been subjected to much greater transportation. The exact extent of this has not been determined, but it has probably amounted to many times the distance of the carriage of the materials which form the till.

A large part of the waste which enters into the composition of the drift of this district has come from the disintegration of the conglomerates of the Carboniferous section. This is shown by the fact that a considerable portion of the drift pebbles retain the distinct form which was given to them by the stresses to which they were subjected in the beds in which they had lain so long, and also by the fact that these pebbles are often composed of the fossiliferous quartzite which yielded so much to the débris in the Carboniferous time, but does not now exist in the original bedded form in any part of the district. The fact that the glacial deposit in the older moraines

contains relatively few large bowlders which have been derived from the conglomerate, while the pebbles from that source are extremely abundant, is worthy of note. Thus, on Marthas Vineyard, where the bowlders and pebbles which lie on the Cretaceous and Tertiary rocks have all been imported from the Narragansett Basin, the amount of pebbles which have been separated from the matrix of conglomerate is very great, but the number of bowlders of the conglomerate rock is so limited that an inspection of a thousand of these erratics revealed only half a dozen of this nature, the others being from the granitic and other old rocks which form the margins of the basin or from some of its inliers of like rocks. In its ordinary undecayed state the conglomerate fractures in such a manner that the rift intersects the embedded pebbles. We are therefore justified in believing that at the time the glacial flow began to attack this region the deposits were decayed to a considerable depth, so that the attrition broke up the adhesions and separated the pebbles from the matrix. The fact that the bowlders of the massive conglomerate are very rare in the moraine of Marthas Vineyard, which was formed at an early stage of the ice time, while they are relatively much more common in the drift lying in the basin, gives support to this view. It is certain that the débris from this basin which is found in Marthas Vineyard was derived from the area in the earlier stages of the glacial excavation, while that formed on the surface of the conglomerate represents, of course, the last part of the erosion which was effected.

AMOUNT OF EROSION.

Although the amount of erosion which was accomplished by the ice in the last Glacial epoch can not well be determined, the evidence goes to show that it was considerable. Thus the moraines in Falmouth and on the island of Marthas Vineyard and the Elizabethan group, all of which appear to owe their materials in the main to the rocks of the basin and its margins, contain in the aggregate a mass of matter which, evenly distributed over the basin, would cover it to the depth of several feet. It is not to be believed that these accumulations represent anything like half the rocky matter which was worn away from the Narragansett district. Better evidence as to the amount of erosion, as well as much information concerning the distance to which the drift has been carried, is afforded by the bowlder trains of this field. These trains are traceable from certain of the peculiar

deposits of the district to distances which vary with the endurance of the particular kinds of rock. The crystalline limestones of Lincoln form trains having a traceable length of from 4 to 5 miles; after a journey of that length the rather soft bowlders seem to be quite worn out. The exceedingly hard ilmenitic magnetite which occurs in Cumberland near Woonsocket, Rhode Island, has yielded the most perfect bowlder train that has yet been traced in this section of the country. Originating in a deposit which has a width transverse to the path of the ice of only a few hundred feet, this train extends in a gradually broadening path to the outer or southern part of Narragansett Bay in a nearly north-and-south course; thence it appears to have been deflected easterly, so that it overlapped the western peninsula of Marthas Vineyard, known as Gay Head. In that district four or five specimens of the unmistakable rock have been found, which afford sufficient evidence that the train extended at least 60 miles from the point of origin.

In a description of the Iron Hill bowlder train,[1] I have given a detailed account of its phenomena; and an estimate, based on such data as were obtainable that served to show the amount of the rock in the deposit, was that the amount of erosion which had taken place at Cumberland Hill during the Glacial epoch was not less than 60 feet. In reviewing the facts, it seems to be evident that this estimate is under rather than over the truth. It is not unlikely that if all the waste from this elevation which was removed by ice action could be restored, the summit would be near 200 feet above the present level. It is not to be supposed that the amount of erosion in the Narragansett area was as great as that which occurred at Iron Hill. At the time the ice began to act, that mass was probably at a much higher level in relation to the surrounding country than it is at present; it is likely that the processes of decay had penetrated deeply along the numerous joints, so that when assailed by the ice it rapidly broke up. However, making what seems to be all due allowance for this probably greater erosion in this point, it must be confessed that, taken with the evidence before adduced, it serves to show that a considerable thickness of beds, perhaps near 100 feet of rock, must have been worn from this area during the time the ice lay upon it.

[1]The conditions of erosion beneath deep glaciers, based upon a study of the bowlder train from Iron Hill, Cumberland, Rhode Island, by N. S. Shaler: Bull. Mus. Comp. Zoöl. Harvard Coll., Vol. XVI, No. 11, January, 1893, pp. 185–225, 4 pls. and map.

It is well to contrast the rapid and effective erosion work of the continental glacier with the relatively very slight action that free water or atmospheric decay has had upon the rocks of this district since the ice mantle passed from its surface. Since the surface entered on its present state there has been but very little decay of the rocks. Even where they have remained without a covering of soil, as is the case in the summit of Iron Hill, the penetration of decay in most instances is inconsiderable, and the actual loss of material is so slight that the lowering of the surface has not on the average exceeded 2 or 3 inches. In some cases bosses of the harder conglomerate which have had no other protection than a coating of lichens and the thin layer of detritus which they gather on a steep slope, still retain the deeper groovings which the ice impressed on them. So far as the bed rocks are concerned, the removal of matter from this region since the close of the last Glacial period has been entirely unimportant, and the decay, such as has penetrated so deeply in the Southern States, has hardly begun even in the most advantageous situations for the process. These facts point to the conclusion that the period which has elapsed since the ice left this district has been, in a geologic sense, very brief.

It is to be noted that the channels in which the main arms of Narragansett Bay lie are still rather deep, though their bottoms are probably covered by a considerable thickness of drift materials, both that which was originally deposited when the ice was retreating and that which has been swept to its place by tidal action. The question suggests itself as to what extent these depressions are due to the direct cutting action of the ice and what to the concomitant action of the subglacial streams. While it must be admitted that the general distribution of the channels of the bay and their relation to the river channels connected therewith favor the supposition that the arrangement of the valleys is in the main the result of ordinary river action, it can not well be denied that the glacial work greatly changed the forms and in a measure the distributions of these depressions. Thus the several rocky islands of the bay, with deep water between them, can not well be explained by the supposition that they are the remains of divides which once separated adjacent parallel river valleys. The channel between Bristol Neck and the north end of Aquidneck Island appears to be inexplicable on the theory of a submergence of river topography, but it may be accounted for on the assumption that it is due to glacial scouring.

It is to be noted that the general form of the basin is such that the ice during the period when its front lay beyond the present shore line of the continent, as it probably did for the greater part of the time in which it occupied this part of the country, was led somewhat to concentrate its flow in the relatively narrow space occupied by the seaward part of the basin. This concentration must have increased the speed of the movement and thereby the erosive effect of the moving ice. I have elsewhere[1] endeavored to show, by clearer examples than are afforded by this field, that the effect of such an increase of speed, due to the crowding of ice into a relatively narrow way, is to intensify the erosive work which the ice performs. It is also clear that the subglacial streams which discharged into this bay were very large. Such streams, so long as they flow beneath the ice, probably have a far greater cutting power than open-air rivers, for the reason that they move with an energy in some measure intensified by the height of the column of ice whence they are derived. As the sheet may well have had a depth of some thousand feet, the impulse can be accounted as great. These subglacial streams were competent to urge forward over level ground the bowlders, often several feet in diameter, which we now find embedded in the eskers—masses which the most vigorous mountain torrent would hardly be able to move. We may therefore reckon the subglacial streams as powerful agents of erosion, quite competent to deepen channels such as the preglacial rivers may have formed or to cut new ways if the conditions compelled them to flow in other courses.

It must be said that the form of Narragansett Bay is not that of a characteristic fiord, such as in the regions farther to the northward clearly attest the competency of glacial ice to excavate such basins. There is no trace of the sill or rock barrier across the mouth of the bay, separating it from the sea, such as marks the normal Scandinavian fiords. We may, however, hold that while this Narragansett system of depressions is clearly, as regards its general outlines, the product of erosion work done before the ice time, it owes much of its form to glacial processes.

Before closing this brief account of the glacial phenomena of the Narragansett district which demand notice in this memoir, we may refer to the general form of the surface of the basin with reference to the possible effect

[1] The geology of the island of Mount Desert, Maine, by N. S. Shaler: Eighth Ann. Rept. U. S. Geol. Survey, Part II, 1889, pp. 1007, et seq.

of ice action in shaping the area. The facts presented in this report clearly indicate that the bed rocks have been cast into exceedingly varied flexures and faultings. As these disturbances involved a great thickness of strata and were made apparently in a geologically short period, the result must have been the formation of mountains of high relief. Yet these elevations have been so completely effaced that, as is shown in the maps, the region is now in the state of a great plain, the trifling differences of elevation being due to the action of the rivers and the subglacial streams. As before remarked, the modern school of geographers would attribute this topographic character to the process of base-leveling, by which, through the atmospheric agents of erosion, a surface, however diversified, tends inevitably to be lowered to near the level of the sea. Making what seems to be due allowance for the effect of repeated elevation in refreshing the work of the streams and thus promoting the degradation of a country, a cause which most likely operated in the West Appalachians more effectively than on this seashore, there still seem to be needed some agents to explain the remarkable planation of the district we are considering. It is likely that glaciation has been one of those auxiliary agents. We will now consider the way in which it may have operated to bring planation about.

The evidence has been noted which goes to show that the rocks of this basin were deeply decayed at the time the work of the last Glacial period began. Acting on such a surface, the ice would quickly become burdened with an excess of débris, in which state it would resemble an ordinary stream of water which has a charge of sediments much greater than it can carry. In this case both the fluid and the viscous streams necessarily tend to deposit a part of their burden and to flow over the accumulations, being thus in part excluded from contact with the bed rock. The deposits of the overburden would naturally take place in the valleys, the floors of which, except when attacked by the subglacial streams, would remain uneroded, while the higher-lying parts of the field would be cut away. As the process of erosion advanced and the waste from the elevated places became smaller in quantity, the glacier would be free to attack the lower levels. The result of this succession of events would be to level off the inequalities of a country which, owing to the decayed state of the rocks at the time the ice came upon it, afforded detritus more rapidly than the machinery of transportation could bear it away. It may be remarked that the apparently excessive

degradation of Iron Hill, as above noted, can be explained in this way. It therefore seems reasonable to adduce ice work as one of the agents which have served to bring about the destruction of the original topographic reliefs of this district.

Along with base-leveling and ice work, there is another class of agents which have doubtless operated with much effect in bringing the district into its planed-down state. These are the forces which act at and below the level of the sea. There can be no question that the effect of the surf and the shore currents is to plane off the rocks and to bring about such topographic conditions as are found in this basin. The only doubt is as to the rate at which the work may go on. Judging by the speed with which the benching action of the sea proceeds where the attack is delivered on hard (i. e., undecayed) rocks, geologists have generally assumed that the aggregate work which is due to this action is relatively small, that it plays no important part as compared with base-leveling due to atmospheric agents. We must remember, however, that what we know of the extent of superficial decay in this and other countries requires us to believe that in the oscillations of the continents it must often happen that deep sections of rocks which have been made very friable are exposed to the mill of the surf. In this case it is fair to presume that they might be swept away with something like the speed which is exhibited in the disintegration of the Pliocene cliffs of Marthas Vineyard. When they face the open sea, these deposits, in coherence comparable to the decayed beds of the Southern Appalachians, are retreating at the rate of about 3 feet per annum, as determined by fifty years' observations. At this rate the surf mill would be able to work inward across the field of the Narragansett Basin in less than one hundred thousand years.

CHAPTER IV.

ECONOMIC RESOURCES OF THE BASIN.

The economic resources of the basin include the soils, the pottery clays, a limited range of building stones, certain iron ores, and the coal beds of the Carboniferous series.

SOILS.

The soils of this region, being in the main of glacial origin, have the economic stamp of deposits which are more or less directly related to the ice work. When, as is the case in the greater part of the district which lies at more than 50 feet above the sea, as well as in much of the lower ground, the soil rests upon bowlder clay, its fertility depends to a great extent on the nature of the subjacent rock. If this be conglomerate, as is the case over a large part of the central portion of the basin, the soil, because of the generally insoluble nature of the detritus from these beds, is characteristically lean. When it rests upon sandstones it is of moderate fertility. Where, as in the region about Newport, and generally on Aquidneck Island, the underlying rock is of shale, the soil is of more than usual value. The considerable organic matter of these beds apparently serves to make a richer field for the plants.

As compared with other portions of New England, this basin abounds in glacial sand plains. These occupy the larger part of the surface below the level of 50 feet above the sea, and a considerable area of higher-lying ground. The relatively great extent of these plains seems to be due to the fact that the existence of the extensive depression of the Narragansett Bay made it the point of discharge of streams collected beneath the glacier, which bore great quantities of débris beyond the retreating ice front and deposited the sandy portion of this detritus in the shallow water of the sea, which then covered the area. These sand plains are composed mainly of siliceous materials, and afford infertile soils. They are, however, of a quick

nature, responding at once to manuring. Moreover, they are readily, though temporarily, much improved by plowing in green crops, the store of vegetable matter thus introduced into the earth serving to promote the solution of the feldspar, mica, etc., which exist in the mass, though the quantity is not considerable. These sand-plain soils, because of the absence of bowlders, are easily tilled; they can at certain points be readily irrigated; and they thus are likely in the modern time of intensive agriculture to be valued more highly than heretofore.

The inundated lands of this district include a small area of marine marshes and a considerable extent of fresh-water swamps. On account of the limited range of the tides along this part of the coast, the reclamation of the marshes can not be easily effected by diking. These areas will therefore not receive further consideration. The fresh-water swamps, including in this group all the lands which are made untillable by temporary flooding in the planting season, occupy an aggregate area of about 45 square miles, or nearly 28,000 acres. The larger part of this swamp area is to a greater or less extent used as a source of water supply for mills, the waste of the flood times being there stored for use in droughts. Until this use of the swamps is abandoned it will not be possible to win any large portion of these over-watered soils to agricultural use. About one-third of the total area consists of bogs of limited extent, which do not serve as reservoirs and are therefore open to improvement. In most instances these fields can be readily drained by means of inexpensive ditches. When so unwatered, the areas afford soils of two distinct groups. Around the margins of each area there is normally a belt where the peaty matter has not accumulated to a thickness of more than a foot, and where, after being allowed to dry, and consequently to shrink, it can, by deep plowing, be incorporated into the soil. In these portions of the drained swamps tillable fields of very superior quality may be obtained. Within the area of the basin there is probably a total extent of not less than 6,000 acres that is thus available for agriculture. Such ground is remarkably well adapted to market gardening. When the peat of a drained bog much exceeds a foot in thickness, it is difficult to reduce the area to ordinary tillage. The only effective way of accomplishing this result is by securing conditions of exceeding dryness by extensive ditchings, after which the peat may be burned, as is done in northern Europe. In the present condition of our

agriculture this method may be deemed inapplicable. Therefore the only use which can be made of these bogs is for plantations of cranberries. In the method of cultivation which is commonly employed with that plant, several thousand acres of these drainable lands, especially the areas in the eastern parts of the basin, are well fitted to this mode of tillage.

COALS.

The coal beds of the Carboniferous series afford the most important economic resources of the basin. As is indicated in the portions of this memoir which have been prepared by Messrs. Foerste and Woodworth, these beds are probably limited to the lower half or shale-bearing portions of the great section. So far as is known, no deposits of any importance exist in the zone of the upper conglomerates. The exhibition of these coals is the clearest in the region where they have been most extensively mined, on the western side of the northern part of Aquidneck Island. At this point they are seen dipping to the eastward near the surface at an average angle of about 30°, with a diminishing slope as the workings penetrate toward the center of the syncline. In this section at least two coal beds occur, the lowest of which is about 2,000 feet below the base of the upper conglomerates, and the highest within perhaps 1,000 feet of that line.

In the western and northern parts of the basin the same or other coal beds occur. Of these, the deposits in or near Pawtucket and at Cranston are the best known. The bed at Pawtucket—there seems to be but one—lies apparently several thousand feet farther down in the great section than the beds of Aquidneck. It is likely that this bed is continued southwardly near the margin of the basin to near its southern end, and that the various exposures which have from time to time been made along this line lie upon it. It is also probable that the coal along the northern part of that border, as far as Wrentham, is of the same or a closely related stratum.

The bed of coal in Cranston may most reasonably be regarded as equivalent to one of those in the Aquidneck section. Its position in relation to the upper conglomerates, however, can not be ascertained with any certainty; so its place must be left in doubt.

The coal beds which were at one time worked in Mansfield are in such a position that they can not be safely placed in reference to the other known deposits. The relation of the beds to one another and to the immediate

section in which they lie inclines the observer to the opinion that they are the equivalents of the uppermost at the mines on Aquidneck Island; but this opinion has little evidence to support it.

Many other deposits of coal have been occasionally exposed in various parts of the field in which the carbonaceous strata occur. Some of these, as, for instance, the beds at Bristol, have been made the objects of experimental mining. The last-named deposit is, from its position, to be reckoned in the group occurring in the northern part of Aquidneck, but the greater part of these little-known occurrences can only be placed as below the upper conglomerate.

CONDITION OF BEDS.

As none of the coal beds of this district have been worked for many years, the accounts of the deposits can not be made anew. The writer has seen the bed which was last worked at the Aquidneck mines, and also that at Valley Falls, which to within a few years ago was mined for "foundry facings," and also that which was in a small way exploited at Cranston in an unavailing effort to market it as fuel. From these observations and the imperfect records which exist of the facts concerning the other deposits, the following statements may be made as to the physical conditions of the deposits.

The coal beds of this area probably number a half dozen or more, of which only those of the Aquidneck group have been proved to have much continuity. Owing to a feature which, so far as observed, they all present, the thickness of none of these beds can be accurately determined. This feature is the peculiar "rolling" to which the carbonaceous material has been subjected in the dislocation of the beds of which it forms a part. In practically all cases the beds above the coal have been by the process of metamorphism brought into a very compact and rigid state. This change appears to have taken place before or during the development of the folds into which they have been cast. As the process of dislocation went on, the irregular strains acting on the relatively little resisting coal caused it to creep toward the points of least pressure. The result was that wherever the bed has been followed in the direction of the dip for a considerable distance the layer is found to widen and contract, so that in a variable length

of from a few score to 600 or 800 feet it may pass from a mere trace to the thickness of 20 feet or more, the cross section having a rudely lenticular form. Followed horizontally, these thick portions of the vein thin toward either end—at least that is the impression made by a study of the Portsmouth mine. So far as could be seen there, the horizontal dimension of the lens was much greater than that shown in descending the slope. It is evident that these conditions exclude any careful study as to the thickness of the beds. It may be said that a rough computation of the contents of the principal bed mined at Portsmouth showed it to be probable that the thickness of the deposit before it was disturbed by the shearing action was not far from 4½ feet.

It need not be said that this irregular form of the coal deposits, combined, as it is, with a certain amount of faulting, which, though not distinctly shown in the small workings, is evident in the structure of the field, makes it important to determine how far these features are general throughout the basin. On this point the information is very scanty. It may be said, however, that where, as in the Portsmouth mine, the workings had gone for a distance of about 1,400 feet from the outcrop, and where the steepness and the dip considerably lessened with the approach to the center of the syncline, the irregularity of the bed had perceptibly diminished, giving some reason to expect that there was an extensive area of coal in that central part of the trough which had not been much dislocated. Unfortunately, this is the only portion of the basin where there is sufficient basis for reckoning that the coals within reach of mining work occupy a position which gives them the chance of escaping the effects of "rolling."

Owing to the lack of detailed knowledge concerning the position of the coals, or even of the precise attitude of the rocks in this basin, it is not yet possible to estimate with any approach to accuracy the area in which coals of workable thickness may be found. It may be said in general that all parts of the section lying more than 2,000 feet below the base of the upper conglomerates show, from point to point, traces of coal. Considering the numbers of these chance exposures, and noting the general way in which the portions of the section containing coal are hidden by glacial detritus, there is reason to believe that a considerable part of the rocks below the indicated level are in some measure coal bearing. Definite

information as to the extent and thickness of these beds can not be had without extensive and systematic exploration with the drill, but some results could be obtained by well-planned superficial excavations.

It should be noted that, owing to the thickness of the barren upper part of the section of the rocks in the basin, nearly one-fourth of its area has the coal-bearing beds so deeply buried that they are below the level where they could be mined; in much of the area the estimated depth exceeds 10,000 feet. Moreover, nearly another fourth of this area is occupied by the waters of the sea, so that it may be regarded as impracticable to explore the underlying rocks. The remaining half is fairly open to inquiry provided there should be found a market for coal of the peculiar quality which it affords, at a cost which would be imposed by its physical and chemical conditions. These we will now note:

CHARACTERISTICS OF THE COALS.

Wherever found, the coal of this basin has certain characteristics which distinctly separate it from any other fossil fuel that has been mined in this country. The material is everywhere extremely anthracitic, often ranging in appearance toward graphite. It is usually much penetrated by veins of varied and rather complicated nature. It is high in ash, the proportion commonly being 10 per cent, and often attaining to near twice that amount. This ash contains in most instances a singularly large amount of lime, which causes the cinders to smelt and thus clog the grate bars of a stove or boiler furnace. As is shown by the accompanying analysis, the percentage of fixed carbon is abnormally high, yet an extended trial of the coal in producing steam showed that the value for this purpose was but 72 per cent of that of Lackawanna coal. The reason for this disproportion may have been in part the lack of adaptation of the fire boxes to the character of the fuel, which evidently needs a very strong draft, and the fusible nature of the slag, which makes it difficult to keep the grate bars clean. It is possible, however, that a portion of the carbon is in some special chemical state which hinders its ready combination with oxygen, perhaps in the condition of the supposed graphitic acid of Graham.

Analyses of coal from the Portsmouth mine, Portsmouth, Rhode Island.[1]

[Analysts, Dr. F. A. Gooch and Mr. B. T. Putnam.]

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Water	5.12	0.52	3.18	2.25	7.62	7.96	8.76	10.27	10.47
Volatile combustible	6.49	6.31	4.43	6.46	5.42	4.95	7.23	5.99	5.83
Carbon	71.04	76.23	75.97	79.59	74.40	76.22	70.24	67.50	66.95
Ash	17.35	16.94	16.42	11.70	12.56	10.87	13.77	16.24	17.05
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sulphur	0.216	0.224	0.258	0.643	0.28				
Ash	Red.	Red.	Red.	Red.		Red.	Red.		
Fuel ratio $\left(\frac{\text{Carb.}}{\text{Vol. Comb.}}\right)$	10.94	12.08	17.14	12.32	13.72	15.39	9.71	11.26	11.48

I. Bottom of shaft, north side; thickness of seam, 3 feet 11 inches.

II. Bottom of shaft, south side; thickness of seam, 2 feet 7 inches.

III. South side, 50 feet from bottom; thickness of seam, 6 feet.

IV. South gallery, 370 feet from bottom; upper three-fourths of 6-foot seam.

(Analyses I, II, III, and IV are from samples taken across the width of the seam.)

V. The average of seven analyses made from samples taken at intervals along the length of a 6-foot drill core, cut out of what is known as the "back seam," at about 90 feet below the mouth of the Portsmouth mine.

VI and VII. The single analyses of this series showing the maximum and minimum percentages of carbon and ash.

VIII and IX. Samples taken from two lots, of several tons each, of freshly mined coal used in other experiments.

Although it is probable that if the coal can be mined in the undisturbed central parts of the shallower synclines it will there be found to contain less vein matter, and hence will be lower in ash, its high percentage of the latter and its other objectionable peculiarities may have to be reckoned as insuperable. It is therefore very doubtful whether it can ever be brought into service for ordinary uses. The experiments heretofore referred to appear to show that it can not be given a fair place for steaming purposes. The fact that while the Portsmouth mine was working, the people of the neighborhood were not willing to pay more than two-thirds of the cost of Pennsylvania anthracite for its product, shows that it is not well suited for household use. There remain, however, as before remarked, certain fields in which this fuel may well find a place. These are ore smelting, the manufacture of water gas, and the process of burning brick when the powdered coal is placed between the layers of the kiln.

[1] Notes on the Rhode Island and Massachusetts coals, by A. B. Emmons: Trans. Am. Inst. Min. Eng., Vol. XIII, 1885, p. 511.

As to the first of the aforenamed uses, it may be said that the coal of this basin seems to be fairly well suited to the needs of smelting. It is low in sulphur; its specific gravity is so high that it will give a large number of heat units for a given bulk; the ash, though high, is, owing to its composition, easily smelted. I was told by the person who owned the mine at Portsmouth the greater part of the time during which it was worked, that the coal was the best that could be obtained for smelting copper ores as well as for the subsequent working of that metal. The further statement was made that a cargo of the fuel had been sent to an iron furnace on the Hudson and that it proved very satisfactory as compared with the anthracite of Pennsylvania in making Bessemer pig. I was also informed by one of the Crocker Brothers of Taunton, Massachusetts, who worked the mine, that a test of a few tons of the coal had been made in the manufacture of water gas and that it was well suited to the purpose. It is not now possible to verify these statements, but they appear to be quite consistent with what is known of the nature of the anthracite of this field.

The only undetermined qualification of the Narragansett coals as regards their use in the special arts above mentioned is that observed by Dr. Arthur B. Emmons and described in the paper referred to. This, in the words of the author, is "the striking peculiarity (hitherto unnoticed in anthracite coals, or, I believe, in any coals) of quickly taking up a large percentage of water under a moist condition of the atmosphere and as readily parting with it under a drier condition of the atmosphere." According to the records obtained by Dr. Emmons and his collaborator, Dr. F. A. Gooch, the Narragansett coal may, with the changes in the humidity of the air, vary as much as 15 per cent of the whole weight of the material. How far this peculiarity may affect the value of the coal in the smelter or water-gas converter will have to be determined in an experimental way.

In considering the prospective value of this coal, the cost of mining it is of course a matter of much importance. So far the practical experiments in mining have been too few and too imperfectly executed to afford any clear determination. The mine at Portsmouth, the only one in the basin maintained in operation for any considerable time, was not well managed. As the deep part of the pit was almost absolutely dry, the little water found in it entering from the old upper workings, there was but slight expense for pumping, the drip collected in the sump being hauled about once a month

in one car. The roofs of the seam were admirably strong, requiring practically no timbering even where the pillars were robbed to a very extreme point. At the time I last examined the place the best information which could be had indicated that the cost of lifting the coal and treating it at the breaker amounted to about $2.50 a ton. An estimate based on a suitable amount of surface plant and proper approaches to the vein, with a fit administration, indicated that at the present price of labor the coal could be mined, so long as the bed was in the then existing favorable position, for about one-half the sum it was then costing. If the coal is found as a little-distorted bed, averaging say 4 feet thick over as much as 3 square miles in the central part of the basin, it should by means of vertical shafts be possible to mine it at a yet lower cost than that named.

CONDITIONS OF FUTURE ECONOMIC WORK.

As to the best places for future exploration, it may be said that it seems to be undesirable to undertake any further search for the coal at the outcrops, the presumption and the evidence being alike in favor of the opinion that at such places the coal, lying at a steep dip, is more likely to be much infiltered with vein matter. The aim should be to seek the beds in the central parts of the synclines, or where, though monoclinal, the strata have a low dip.

The best of these places appears to be that in the northern part of Aquidneck Island. If the apparent diminution in the slope of the strata toward the center of this trough be verified, there is a reason, before remarked, to expect a considerable area of the coal beds in the central part of the northern end of the island, where the rocks seem a little disturbed. There is no very clear evidence as to the depth below the surface at which the coal may lie, but it seems quite probable that this depth is less than 1,800 feet in the central portion of the area. To determine the true position of the deposits, a line of borings should be carried across this part of Aquidneck Island in a nearly east-west direction, with its western end about 500 feet from the vertical plane where the old workings stopped. It will be well to supplement the information thus gained, especially if the indications so obtained are favorable, by other borings carried southward toward Quaker Hill.

The next most promising field for exploration is the belt of country lying immediately to the east of the northward extension of the Providence

River, where, if the determinations of the structure as set forth in this report are correct, the equivalents of the Portsmouth coal beds should be found. The known facts go to show that in this part of the field the rocks are not much disturbed, and that these coal beds are in the place where it is supposed they should occur. Should these suppositions be verified, there may be an area of 20 or more square miles in which the conditions are favorable for mining operations. In connection with this part of the field, it is necessary to set forth the facts concerning a boring made in the town of Seekonk about twenty-five years ago. This gave a section of the rocks which at its base appeared to indicate the occurrence of a bed of fairly good anthracite at a depth of about 700 feet below the surface of the ground. There can be no doubt as to the fact that the boring was made. Abundant samples of the core were examined by the writer about five years after the work was done. They were then in the possession of the man on whose land the boring was made. They showed the rocks to be of the general character of those which overlie the Portsmouth beds, and also that the beds are not very much disturbed, the dip averaging not more than 20°, probably to the eastward. An analysis of the coal showed it to have the general character of the Rhode Island deposits, being extremely anthracitic. Mr. Emmons, in the paper above referred to, states that, while the boring down to the level of the coal is the result of an honest inquiry, the coal is a fiction, the portion of the core showing the coal having been made on the ground by operating the drill several times through a large lump of coal brought by the disappointed explorer to the man who was managing the apparatus, ostensibly to find whether the instrument would cut a clean core in material of that degree of hardness. On review of all the facts, it appears worth while to reopen this drill hole, which was carefully plugged at the time the work was abandoned, and, with a reamer, to test the bottom of the opening, in order to ascertain the truth. If coal is not found, it will still be well to continue the drill work already done, downward as far as it may be conveniently possible to do so, for the reason that not far below the base of the present opening we may expect to penetrate the portion of the section where the beds of the Portsmouth district belong. If the section could be carried to the depth of say 3,000 feet, the information would be of great value as related to the possibility of finding workable coal in the northern portion of the basin.

By reference to the map (Pl. XVII) it will be seen that the upper conglomerates occupy an insular position in the northern part of the basin, in which they have been left by the degradation of the folds in which they lie. So far as has been learned, there are no faults or other local disturbances which should make it improbable that the beds equivalent to the Portsmouth coal-bearing part of the section are found in their due place in the belt of country on the north and east of this conglomerate area. It is to be noted, however, that so far no coal beds have been revealed in this belt by natural exposure or by chance excavations; but this may be accounted for by the fact that the district is much more deeply covered by the drift mantle than that to the westward and northward. Therefore this section, within say a mile of the margin of the upper conglomerates, may be regarded as next in promise to the sections before mentioned as a field for explorations. It should be observed that the angle of the dip toward the center of the Taunton or Great Meadow Hill syncline (see figs. 8, 9, in Part II of this monograph, pp. 122, 123) makes it probable that at a little distance within the margin of the coarse conglomerates the coal beds which would lie in the strata plane of those at Portsmouth would be greatly below the level where they could be profitably worked.

As yet no adequate information has been attained which may serve to show the conditions of the basin in the region to the east of the city of Taunton. In that place a boring carried to the depth of 850 feet revealed no good coal; indeed, but little more than carbonaceous matter was found. The beds are presumably the equivalent of those which, in a thickness of 2,000 feet or more, overlie the coals of the Portsmouth mines. The churn drill gave, of course, no information as to the attitude of the rocks. It seems likely that there are but slight faults or folds in this part of the field, and that in the main the beds belong to the section which may be expected to contain coals.

For the reasons before given, which go to show that it is not worth while further to explore for coal around the margins of the basin, there remains only one other portion of its area to consider. This is the field between Aquidneck Island and the western shore of Narragansett Bay. The greater part of this district is covered by water. All that part of it which lies to the south of the northern end of Canonicut Island is evidently so affected by regional metamorphism that any coal which it may contain is

likely to be of very poor quality. The water-covered area is, as before noted, difficult to explore. If, however, coal should eventually be found beneath those arms of the sea, it could doubtless be mined with safety, though with added cost, on account of the difficulties of access.

Before any further costly effort to develop the coal deposits of this district is made the coal from some one of the openings—that at Portsmouth, for instance—should be subjected to systematic and thorough experiments to determine its value in the wide range of arts to which this fuel may be applied. These tests should include at least the arts of ore smelting and the manufacture of water gas, brick, and pottery. Experiments, which on theoretical grounds appear to be very promising, should be made in crushing and washing the coal and in subsequently converting it into briquettes. It may be found that in this form the material will prove serviceable as an ordinary fuel. There can be little doubt that this inquiry should be undertaken. As before noted, there is a very large amount of coal in this basin, although there is no basis of reckoning the total quantity with any approach to accuracy. There can be little doubt that it is to be estimated by the hundred million tons. Even though, as has been assumed, this coal can not compete in ordinary uses with that which is imported, the chance that it may serve in many important arts affords full warrant for a careful study of its quality and distribution.

The inquiry above noted could be undertaken on a lesser scale, limiting it to the Portsmouth field. As already stated, this is a typical area, probably the best in the basin. Work there should first be directed to ascertaining the extent, condition, and depth at which the coals occur in the central portion of the trough in which they lie. If the results obtained are satisfying, it will be easy to obtain from the existing openings enough coal to make the trials which have been suggested. Supposing these tests to show economic value, the old workings should be abandoned and the beds approached by means of a vertical shaft, so placed as to enter them as near as possible to the center of the basin.

IRON ORES.

The iron ores on the western border of the Narragansett Basin have a certain amount of economic interest, in that, in case the coal is ever developed, they may become of value for the purpose of mixing with the

ore brought from other parts of this country or from abroad. The only iron ore of promise in this field is that which occurs at the eminence known as Iron Hill, which lies in the town of Cumberland, about $2\frac{1}{2}$ miles east from Woonsocket, Rhode Island. The deposit is a rather ilmenitic magnetite,[1] containing about 35 or 40 per cent of metallic iron, but it is remarkably free from phosphorus, in this regard closely resembling the best Swedish ore, which it also resembles in its petrographical characters. The mass of the ore, apparently in its nature a dike, runs along the general surface of the country in which it lies, to the height of nearly 100 feet. It has a width of about 600 feet and is of about twice that length. It is probably continued downward to an indefinite depth, and may extend for a considerable distance beneath the cover of drift to the north and south, in which axis the mass seems to trend. The mass of ore may therefore be reckoned as large; it probably could afford, if desired, a total of 10,000,000 tons or more without particularly deep workings. The limestones of Lincoln, Rhode Island, between Iron Hill and the western margin of the Carboniferous rocks, afford an excellent flux. As they appear in the form of white crystalline marble, it is probable that they also are nonphosphatic. Thus, if the coal of the Narragansett Basin proves to be as useful as a smelting fuel as it promises to be, the shores of the bay may prove to be well equipped for the manufacture of pig iron.

About twenty-five years ago the coal from the Portsmouth mines was to a certain extent used in smelting copper ore which was mainly brought from South America. It was stated when this process was in operation that the fuel was satisfactory. If this was the case, there is yet another reason for supposing that the coal of this basin has a value when used in the reduction of metals. As a whole the evidence thus points to the conclusion that those who undertake to bring these coals into the market will do well to look carefully into the question of their adaptation to this use. If this element of value could be verified, the basis for the development of the deposits might be found without reference to the other ends to which their product might be applied.

In closing these remarks concerning the economic values of mines in the Narragansett Basin, it may be said that, as far as the coal beds are concerned,

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[1] See A microscopical study of the iron ore or peridotite of Iron Mine Hill, Cumberland, R. I., by M. A. Wadsworth: Proc. Boston Soc. Nat. Hist., Vol. XXI, 1883, pp. 194–197.

the developments are not sufficiently advanced to enable the geologist to prove very helpful to those who desire to exploit its resources. Such indications as are here given are therefore to be regarded as suggestions rather than as definite recommendations; the latter can be safely made only when accurately determined facts, such as are obtained from extensive workings, have been gathered.

GEOLOGY OF THE NARRAGANSETT BASIN

Part II.—THE NORTHERN AND EASTERN PORTIONS OF THE BASIN

WITH

A BIBLIOGRAPHY OF THE CAMBRIAN AND CARBONIFEROUS ROCKS OF THE BASIN

By JAY BACKUS WOODWORTH

CONTENTS.

ILLUSTRATIONS

Postscript.—After the pages for this monograph were cast, the writer found in shaly strata opposite Plainville Station, at the base of the fault block described on page 183, the footprints of a small vertebrate, probably an amphibian, associated with rain prints and mud cracks.—J. B. W.

GEOLOGY OF THE NARRAGANSETT BASIN.

PART II.—THE NORTHERN AND EASTERN PORTIONS OF THE BASIN.

By J. B. Woodworth.

CHAPTER I.

THE PROBLEM OF STRATIGRAPHIC SUCCESSION.

In the autumn of 1894 the writer was assigned the task of reporting upon the stratigraphic succession of the Carboniferous deposits in the Narragansett Basin. Previous to this time, during the summer months of 1891 and 1892, he had made an examination of portions of the basin which seemed likely to afford a key to the structure of the beds. In the autumn of 1894 and during the field season of 1895 the examination of the field was continued. The following pages set forth the results of these studies. While more was effected than the writer personally expected, there are many questions yet to be determined regarding the equivalency and thinning out of strata and the tracing of horizons. It is believed that the work so far accomplished serves to afford, first, a truer measure of the thickness of the beds than has heretofore been gained; second, a nearly complete analysis of the structure of the part of the basin studied; and, third, a differentiation of the beds into a few horizons which have a geographical value, if not also in most cases a local chronological value.

The opportunity which the geologist has of determining the succession of the strata in any region usually increases with the amount of uplift and denudation, since, were the beds of a basin to remain in the condition in which they were deposited, the surface of only the topmost stratum would be open to examination. However, if uplift and denudation proceed so far

as to produce excessive complication of structure on the one hand and to remove great thicknesses of strata on the other, the evidence which the geologist seeks for the reconstruction of ancient deposits may be too scanty to permit him to obtain satisfactory results. The stratified rocks of the Narragansett Basin long since ceased to lie in their original attitudes, and so much of them has been carried away by erosion that their stratigraphic succession can be made out only with difficulty and only for limited portions of the field. But these general causes, which, by reason of their long-continued action or their intensity, have worked to the detriment of geological investigation in most mountain-built districts, have in this field been reenforced by local peculiarities arising from the geographical position of the area and from events of recent geological occurrence.

The difficulties encountered in making out a complete and satisfactory succession of the strata of this field may be stated as follows:

REPETITION OF LITHOLOGICAL CHARACTERS.

The duplication in texture and color of sediments widely separated chronologically, but in close juxtaposition, either by superposition through unconformable deposition or by folding and faulting, is a source of doubt where fossils are not present in both terranes. Thus, in North Attleboro, Massachusetts, and northward, in the midst of an area occupied by red Carboniferous shales, sandstones, and conglomerates, there appear red Cambrian shales not to be differentiated in most localities except by means of the contained fossils. Until Cambrian fossils were discovered, the red Cambrian strata were included by all observers with the red series of more recent date.

TRANSITION OF LITHOLOGICAL CHARACTERS.

By gradation in the size of the particles in a stratum, a conglomerate on one side of a denuded anticline or syncline may be represented by a sandstone or shale on the other side of the same broad fold. In like manner, the coloration of beds may vary from one part to another of the same basin, so that strata are no longer distinguishable. In the northwestern part of the Narragansett Basin there are thick beds of red color, having a fairly well defined stratigraphic position. Farther south these beds are replaced by others of dark-gray color, and are even underlain by kinds of beds which in the northern area always overlie the red series.

EFFECTS OF IGNEOUS INTRUSIONS.

Igneous intrusions, by inducing lithological changes, often render the determination of the equivalency of the altered strata a work of much labor, particularly where the alteration is but one of several obstacles to the tracing of the stratigraphy. Where, owing to unfavorable conditions at the present surface, the contact of igneous rocks with stratified rocks can not be observed, much perplexity often arises as to the order of events.

METAMORPHISM.

Dynamic metamorphism has changed both the texture and the coloration of the rocks of extensive sections, thus masking the original sedimentary characters and rendering the recognition of horizons, either by fossils or by lithological peculiarities, difficult. Thus the Carboniferous strata from Wickford north to Providence are highly metamorphosed, while beds of the same age northeastward in the basin are very much less changed from their original condition. Ottrelite-schists in the former area pass into shales in the latter region.

FOLDING AND FAULTING.

While folds and faults directly aid investigation by bringing to the surface strata which would otherwise be concealed, the complete inversion of beds and the separation of blocks of strata by faulting result in confusion. In the series of red strata which occur in North Attleboro the utmost complication has arisen through the degree of folding; and here, also, a block of strata of one series has been thrust into a position where it is surrounded by beds of a different horizon.

DENUDATION.

Where beds are correlated from fold to fold by physical indications, such as the repetition of like beds in the same order and with the same topography, without the aid of fossils, denudation succeeded by local concealment of parts of the series by deposition may lead to erroneous conclusions in the matching of beds. In this basin there is a group of conglomerates found only in synclinal areas; at lower horizons are other conglomerate beds. If denudation should halt upon one of these lower beds where it is exposed in the axis of a syncline, doubt would arise,

without other means of correlation than these physical criteria, as to which horizon formed the axis of the synclinal structure. Where beds have been stripped off from areas several miles in width, as between the Narragansett and Norfolk County basins, there is difficulty in making correlations. Owing to denudation, the uppermost beds of a formation, as originally deposited, may be entirely lost. Thus there is doubt as to the correlation of the upper conglomerates near Newport with those in the Taunton syncline. The Newport conglomerates may be in the position of the left-hand syncline in fig. 3, while those near Taunton correspond to the upper conglomerate in the right-hand syncline.

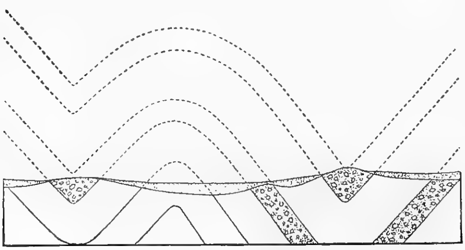

FIG. 3.—Diagram showing misleading synclinal exposures of similar strata.

GLACIATION.

The chief difficulty arising from glaciation is the coating of drift which is left upon the rocks of a country. In the Carboniferous field of southern New England the embarrassment from this source is particularly great, for the reason that the area received a thick coating of the deposits of the retreating ice sheet. So effectually are the bed rocks concealed in parts of the Carboniferous basin, that outcrops may not be seen oftener than from 3 to 5 miles in any direction. The tracing of highly inclined strata along their strike can not be safely undertaken in these areas, and the mapping of the formation must be done with reference to the broadest possible groups, or perhaps be limited to the indication of the presence of undiscriminated members of a large rock series. The distribution of fragments of rock along known lines of glacial carriage is sometimes a help in fixing the boundaries of the underlying bed rocks.[1] In this field the transportation of bowlders was from north to south. Where the rocks trend in bands from east to west, the line along which each different kind of rock appears in the drift is approximately the boundary line

[1] See Fence-wall geology, by A. F. Foerste: Am. Geol., Vol. IV, 1889, pp. 367–371.

between it and the band of rock next north. Where the strata strike in a northerly direction, the fanning out of the drift southward makes the determination of less value; but trains of bowlders thus formed are frequently of great use in checking observations upon isolated outcrops. In using this method less reliance is to be placed upon waterworn drift than upon ice-laid deposits.

SUBMERGENCE.

Recent depression of the land has, in the immediate vicinity of Narragansett Bay, caused the flooding of old valleys, so as to isolate rock areas in the form of islands and to conceal strata which might otherwise be open to examination. To a certain extent this difficulty is compensated by the good exposures in the cliffs formed along the seashore by the action of waves. Such natural sections occur around most of the islands in the bay and along the coast where hard rocks come to the surface, as far north as Providence.

ABSENCE OF ARTIFICIAL EXCAVATIONS.

The almost complete absence of artificial openings, either mines or quarries, in this field at the present day has limited the observations here detailed almost entirely to surface exposures. The quarries which exist are mostly in the granitic rocks bordering the basin, and it is only from the recorded observations of previous workers that information regarding coal mines can be obtained.

It is only by a recognition of these difficulties and their combinations at various localities in this field that the geologist realizes the checks which it is necessary to apply to his work in all stages of its advancement. These difficulties, along with a formerly prevailing misapprehension as to the nature of secondary structure in rocks, are responsible for the general belief among geologists that the strata of this area are too much broken to be unraveled. On taking some of the earlier-drawn sections of the strata of this basin into the field, it will be seen that over considerable areas cleavage was mistaken for stratification, metamorphosed Carboniferous beds were taken for schists of much earlier date, the dips of strata were averaged where they should have been analyzed and separately represented, and more reliance was placed on identity of color than this feature is worth in determining the identity of origin of sediments.

CHAPTER II.

THE PRE-CARBONIFEROUS ROCKS.

ALGONKIAN PERIOD.

BLACKSTONE SERIES.

Primary (limestone and hornblende rock). C. T. Jackson: Report on the Geology and Agriculture of Rhode Island, 1840.

Taconic (Stockbridge limestone, etc.). E. Emmons: Agriculture of New York, Vol. I, 1846, pp. 90–93; also American Geology, Vol. I, 1855, p. 22.

Montalban. W. O. Crosby: Geology of Eastern Massachusetts, 1880, p. 128.

Pre-Cambrian (Huronian?). N. S. Shaler: Bull. Mus. Comp. Zool. Harvard Coll., Vol. XVI, 1888, pp. 15–18.

The above-named writings, with their chronological references, as made at the date of the respective papers, set forth in a word the views advanced regarding the age of the series of limestones, chloritic and hornblendic schists, slates, and quartzites, which occur in the lower portion of the Blackstone Valley and near Providence, within the limits of Rhode Island, along the western border of the Carboniferous basin. It evidently has been the common opinion of geologists that these rocks are older than the Paleozoic series. The names here introduced, without a geological map, are intended as locality terms only.

The Carboniferous strata of this basin rest everywhere unconformably on older rocks, which are found immediately bordering the basin or as small inliers within its limits. These inliers are Cambrian sediments, with associated igneous rocks. The pre-Cambrian or Algonkian rocks above referred to as the Blackstone series occur in the form of highly inclined masses of strata separated and penetrated by granitic intrusions or batholites. The area of these clastic and the associated igneous rocks, now exposed at surface along the western border from Cumberland southward in Rhode Island, is about equally divided between the two groups. The thorough disruption of these ancient strata by changes of attitude and igneous intrusion has produced in the area a type of structure which may

well be termed a batholitic complex. Notwithstanding the irregular disposition of the detached masses of strata, there is traceable a dominant structural system in this belt which is nearly east and west in its trends. The strikes of the strata in the Blackstone Valley are NW.–SE.; those in the area west of Providence, nearly E.–W. Members apparently of an equally ancient system of rocks occur on the southeast of the basin in the gneisses and schists of the New Bedford area (see fig. 7, p. 121), and in small masses near Canton Junction.

The geological relations of the Blackstone series are not exactly defined along the northern and western border. The lowest stratified member along this border of the basin has not been seen, in the area under discussion, to rest on the necessarily older land mass from which it was derived. This separation is probably due to the intrusion of granitic masses.

The determination of the pre-Cambrian age of the group of limestones, schists, slates, and quartzites, in the Blackstone River area, rests upon the relation which it bears to the lower Cambrian strata in North Attleboro. The Olenellus fauna occurs in *little-altered*, red, calcareous shales and slates at this latter place in close proximity to granite (hornblendic granitite). Four miles west of this inlier of the Carboniferous area occur the sediments involved in the complex already described. These strata are *highly altered* sediments, now hornblendic and chloritic schists, mainly of a green color, altered sandstones or quartzites, and crystalline limestones. The presumption that these rocks are pre-Cambrian rests, at present, therefore, on the difference in metamorphism between them and the lower Cambrian rocks in the same field. The criterion appealed to in this case is embodied in the statement that where two sets of rocks coexist in the same dynamic field, that group which has undergone one dynamic movement more than the other is the older. If this view is maintained, this series of rocks falls into the Algonkian. Evidence of unconformity with the lower Cambrian is necessary to make this conclusion positive. The relation of the granitic intrusives to the pre-Cambrian on the one hand and to the Cambrian on the other is simply to show that the granitite is younger than the former, and that the sedimentary rocks are of different ages.

From the typical development of this series in the lower course of the Blackstone River between Woonsocket and Pawtucket, it is here proposed

to refer to the rocks, exclusive of the igneous intrusives, as the Blackstone series. On lithological grounds, which have some support in the stratigraphy, the series may be divided into the Cumberland quartzites, the Ashton schists, and the Smithfield limestones.

CUMBERLAND QUARTZITES.

Bands of quartzite occur as discontinuous outcrops at several localities. The principal of these is traceable from the southern side of Sneech Pond, along the main street southeastward for a mile and a half in the village of Cumberland Hill. The width of outcrop varies from 500 to 1,500 feet. Another small exposure occurs on the same general trend 2 miles north of Ashton. A broad belt of outcrops of the rock occurs in the valley of the Blackstone from Cumberland village southeastward. The quartzite is interbedded with schists or green slates in alternations of varying thickness. The dip of the structure is NE. at angles from 50° upward.

At Albion Mr. F. C. Schrader has observed fragments of the quartzite in a siliceous and quartzitic schist striking about N. 41° W. and dipping 50° NE. Just west of this outcrop, and separated from it by a small ravine, is a large outcrop of the quartzite. The presumption here is that of an unconformable relation of the Ashton schists upon the quartzite. The quartzite is lithologically the same as the Cumberland rock. The fragments of the quartzite in the Ashton schists are sometimes somewhat worn. The schist in the bold bluff on the east of Sneech Pond also contains small, rounded, and broken fragments of the quartzite. These facts, together with the siliceous character of the slates and schists, indicate that they were derived from the erosion of a quartzite terrane. Some evidence of probable unconformity of dip at the Albion locality also points to the conclusion that the more massive quartzite beds of the Blackstone series are older than the Ashton schists.

Limited exposures of quartzite occur along the border in the western part of Providence at Manton. The quartzites are prevailingly brownish-yellow in color wherever they occur, are generally granulated by crushing, and are glossy by reason of the development of some sericite. Their occurrence in lenses and along strike lines, together with the probability that they are older than the Ashton schists, seems to indicate that the

exposures at the present surface are due to the truncation of close-pressed folds in which the quartzites occupy anticlinal axes.

ASHTON SCHISTS.

Reasons have been advanced above which make it probable that the argillaceous rocks of the Blackstone series are the finer sediments succeeding the deposition and partial erosion of the Cumberland quartzites. Distinctions in the several broad bands of these rocks may be based upon the prevalence of siliceous sediment on the one hand and of the chloritic and hornblendic metamorphic products on the other. Not less manifest are differences of secondary structure, on which the slaty and schistose character of the beds in many places depends. All along the border of the area, where the rocks are in contact with granitite and quartz-porphyry, zones of local metamorphism occur in which the characteristic effects of igneous intrusions are to be observed. The series as a whole is characterized by its greenish color. Some of the rocks included in the schists are probably of igneous origin.

SMITHFIELD LIMESTONES.

Owing to the setting off of Lincoln from Smithfield in 1871, the areas of limestone formerly designated by the name here used are no longer in the town of that name. The areas of this rock are isolated, ovoidal in outline, and have no very systematic distribution. In the main, they lie near granitic masses, as between the valleys of the Blackstone and Moshassuck rivers. The areas are a mile or more apart. Those in the area referred to, including Lime Rock, are in general along the same horizon in the Blackstone series. Most of the areas are in the Blackstone Valley, but there are other outcrops south of the Smithfield granitic mass, in North Providence and Cranston.

The limestone are finely granular, dolomitic, crystalline aggregates, and have a laminated structure. Shear zones with development of chloritic minerals are common. The rocks have been subjected to extensive shearing and crushing movements, with the consequent faulting of small dikes, as in the Lime Rock quarries. The limestone occupying the space between these dismembered dikes shows to the eye no trace of the separation. The

disjoined parts of a small dike of amphibolite,[1] probably altered diabase, had, in 1887, the appearance shown in the accompanying diagram (fig. 4).

The contact relations of the limestones with the schists which inclose them have not been satisfactorily determined, by reason of the lack of good exposures. So far as the evidence yet obtained goes, the limestones appear to be of sedimentary origin, though no trace of fossils has been found in them. The lack of continuity in the exposures is probably due to compressive movements in the formation of a closely folded series. It is probable that the ovoidal form of the outcrops as represented on maps would have to be made elliptical, or even pointed at the ends, if better exposures existed.

On the hypothesis of close folding, which alone can account for the great breadth of outcrop of this series on the western side of the Carboniferous basin, the thicker limestones, if newer than the slates, would fall in synclinal axes.

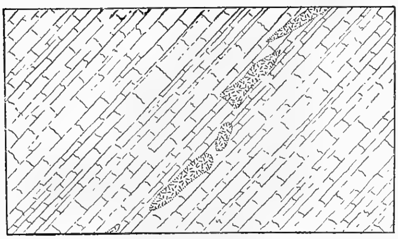

FIG. 4.—Exposure of disconnected dike in Lime Rock quarries, Rhode Island.

In the bed of a small brook above the old iron mine in Cranston a vertical bed of limestone may be seen between the beds of slate. The limestone has a thickness of about 10 feet. It here seems to be an intercalated bed. As yet no facts have been discovered to show whether the limestones are of the same age as or newer than the slates and schists. It is clear that some of the limestones are not older than the argillaceous series.

The most conspicuous feature of the limestone areas is the occasional association with them of metalliferous deposits. The richest and most

[1] Amphibolite from Lincoln. This rock occurs in the southernmost limestone locality at Lincoln, Rhode Island. Microscopic characters: Hornblende occurs in the slide, with extinction parallel to shorter diagonal of rhombs. Chlorite is present in large quantities. Muscovite occurs in confusedly arranged irregular laminæ. Titanite occurs in cleavage forms, derived probably through leucoxene from decomposition of titaniferous magnetite. Magnetite in some areas still exhibits a kernel of the unaltered mineral. Apatite occurs partly or wholly inclosed by the titanite. The highly altered condition of this rock renders its determination doubtful. Quartz occurs in small areas, where it is probably of secondary origin. Notwithstanding the absence of the feldspar constituent, the nature of the hornblende makes it probable that the rock, now an amphibolite, was originally a diabase, like many other highly altered dikes in southern New England.

Mr. Schrader reports other dikes near the western margin of the Blackstone series in the valley of the Moshassuck River. There are also in this field apophyses from the granitic rocks.

varied of these is in the northern part of the town of Cumberland, where, in the area about Sneech Pond, ores of copper and iron occur, replacing portions of the limestone, angular brecciated fragments of which lie in the ore-bearing mass. The iron of the old mine in Cranston, in the "dug-way," is probably a ferruginous replacement of the limestone. The Sneech Pond ore bodies above mentioned are near eruptive rocks, but whether the deposits have originated through the action of heated waters or through the downward percolation of acidulated surface waters, the field itself does not, in the present condition of the openings, give opportunity for determining.

CAMBRIAN PERIOD.

LOWER CAMBRIAN.

Rocks comprised within the limits of the formations now denominated Cambrian were referred to vaguely as early as 1844 by Ebenezer Emmons, but the discovery of demonstrable Cambrian strata in this field was not announced until 1888, when Professor Shaler and Dr. A. F. Foerste published the account of the fossils found by them in North Attleboro, Massachusetts. For a further notice of these rocks the reader is referred to Dr. Foerste's description in Part III of this monograph.

MIDDLE CAMBRIAN.

Beds of Middle Cambrian age have not been discovered south of the area about Weymouth and Braintree, where they are known to occur.

UPPER CAMBRIAN.

(*Not known in place.*)

Postdam. W. B. Rogers: Proc. Boston Soc. Nat. Hist., Vol. VII, 1861, pp. 389–391.
Primordial. Crosby and Barton: Am. Jour. Sci., 3d series, Vol. XX, 1880, pp. 416–420.
Upper Cambrian. C. D. Walcott: Am. Jour. Sci., 4th series, Vol. VI, 1898, pp. 327–328.

In 1861 it was pointed out that the coarse conglomerates of the southern portion of the Carboniferous field contained quartzite pebbles carrying two species of Lingula (*L. prima* and *L. antiqua*) referable to the Potsdam sandstone. In 1880 Crosby and Barton announced the occurrence of *Scolithus linearis* in the same conglomerate pebbles near Newport, Rhode Island.

During the present survey the writer has found these fossiliferous pebbles farther north and east than the localities described by earlier investigators. Other occurrences are noted in Dr. Foerste's section of this

monograph. Lingulæ (now Obolus, see p. 113) were found in a pebble in the red Carboniferous conglomerate on the east bank of Abbots Run, between Lanesville and Arnolds Mills, Rhode Island. Eastward an Obolus pebble was found on the beach near Marshfield, Massachusetts, together with a large fragment of quartzite carrying the long, parallel, closely set burrows of *Scolithus linearis*. Both of these fragments were within the possible range

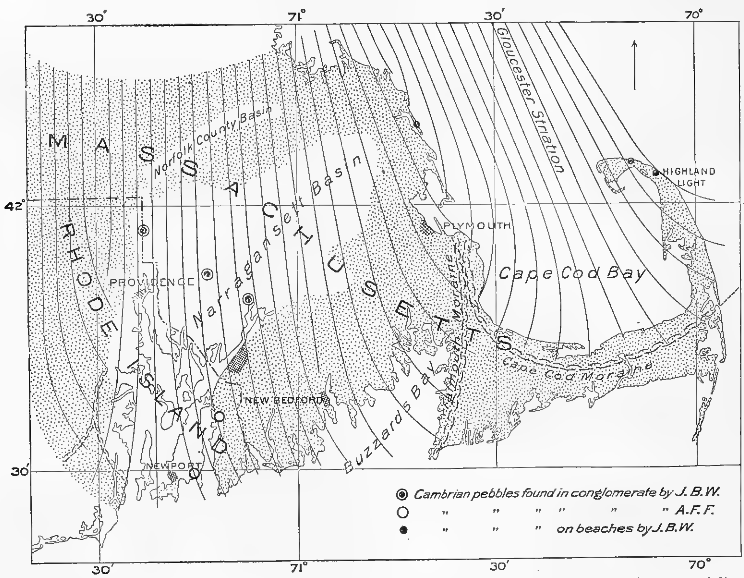

FIG. 5.—Sketch map of distribution of upper Cambrian pebbles. The north-south lines represent the supposed direction of glacial motion during the maximum development of the New England glacier.

of glacial stream drift from the northeasternmost outcrops of Carboniferous conglomerate in the main basin.

In July, 1895, I found a small sand-blasted Obolus pebble on the cliff near Highland Light in Truro, at the northern extremity of Cape Cod; and another pebble, carrying the same brachiopod, was found in an ancient beach on the ocean side of Provincetown. These pebbles are so far to the east of the known Carboniferous conglomerates on the mainland that their derivation from the main basin or from the Norfolk Basin seems improbable, particularly for the reason that the movements of the glacial currents and

the drainage from the ice which were concerned in the distribution of the pebbles seem to demand, in our present knowledge, an origin from some point in Massachusetts Bay, as will be seen from an examination of the accompanying outline map (fig. 5) of the lines of glacial flow in eastern Massachusetts during the time of formation of the Cape Cod moraine. It is true that in the closing stages of ice retreat there are indications about Boston of a more easterly set in the ice, as if it were controlled by the local slope to the sea. If this movement extended as far south as the Duxbury shore, the derivation of the pebbles from the northernmost areas of conglomerate may be accounted for; but these fossiliferous pebbles have not been found as yet in the Norfolk and Boston areas, either in the conglomerates or in the glacial drift, though quartzite pebbles abound. Glacial striæ on a granitic ledge in Marshfield gave a reading of several degrees west of north, but this locality is in the region of the Plymouth interlobate moraine, and does not indicate that the ice moved beyond this line of accumulation in this direction to the eastern shore of Cape Cod Bay.

The Obolus pebbles are very abundant in the beaches of the south coast, as far east as Nantucket and as far west as Block Island, being most common in the intermediate area on Marthas Vineyard. The pebbles have been dispersed southward by the glaciation of the Carboniferous ledges of the mainland.

The earlier reference of these fossiliferous quartzites to the epoch of the Potsdam sandstone has recently been confirmed by Walcott,[1] who states that the brachiopods have their closest affinity in the upper Cambrian fauna of the Newfoundland area. As yet the beds have not been found in situ, an' little else is positively known regarding the upper Cambrian formation of this portion of New England than that which may be inferred from a collection of these pebbles. The information thus obtained may be briefly stated as follows.

Neglecting the question of superposition and the alternation of similar beds with like faunas, data for which matters are of course wanting in the pebbles, the upper Cambrian of the area whence the pebbles came appears to have been composed of at least these three biological divisions:

1. *An Obolus zone of light-colored quartzites.*—The pebbles of this zone exhibit bands, 3 or 4 inches thick, of these gregarious shells, usually preserved as black gra-

[1] Letter to Professor Shaler.

phitic crusts, and less commonly as white calcareous shells. The shells occur mostly as detached valves, with their concave or interior faces turned downward upon the bedding planes, evidently as the result of current action strong enough to invert the shells when their saucer-shaped edges were opposed to the bottom drift, but not powerful enough to move them when their smooth oval backs were presented to the moving water. The existence of currents and shallow-water conditions is further attested by examples of pebbles with marked cross bedding, the "top-set" layers of which, with contained shells, confirm the explanation here given for the position of detached brachiopod valves.

The variations in the quartzites and the irregularities in the fossiliferous layers suggest that this zone alternated with bands of barren quartzite, described as No. 3.

2. A Scolithus linearis zone of light-colored quartzites.—Pebbles carrying Scolithus are by no means so common as the Obolus pebbles; they are most abundant in the beaches of Marthas Vineyard. A cobble found on the beach of Marshfield Neck was 10½ inches long, 6 inches thick, and 6 inches across, the burrows being 6 inches long and worn off at both ends. Walcott notes their absence from the materials which he studied.

3. A barren zone or zones of quartzites of various colors.—Some of the quartzite pebbles included under this head may be of other than upper Cambrian age, since quartzites of different periods occur along the western margin of the basin.

A few quartzite pebbles traversed with quartz veins older than the Carboniferous sediments have been observed, from which it is to be inferred that the upper Cambrian formation underwent some deformation attended by the segregation of silica in veins while the beds were still deeply buried, but under what depth of cover is not exactly known. The presence of Silurian fossils in the Miocene gravels of Marthas Vineyard may indicate the continuance of deposition in this field during the succeeding Silurian period.

Until fossils are found in the quartzites which are known to occur in the outlying region, the exact source of the pebbles in the Carboniferous conglomerates must remain in doubt. It should be noted that the erosion of pre-Carboniferous quartzites has furnished at least three-fourths of the coarse fragmental material in the Carboniferous grits and conglomerates. The area of erosion of so much coarse material, ranging to pebbles a foot or more in diameter, as must have been the case with the now elongated quartzite pebbles of the conglomerate at Newport, could not have been far distant.

While the preponderance of large quartzite pebbles and fossiliferous examples in the southern portion of the Carboniferous field favors the

idea that the derivation was from the south and east, the evidence is good only for the pebbles in that part of the area. The quartz pebbles on the north and west may equally well have been derived from those directions for all that is known regarding the neighboring areas, particularly since the texture of the Carboniferous deposits is mainly consonant with the hypothesis of a peripheral origin of the sediments contained within the present limits of the basin.

In conclusion, it need only be said that there appears to have been nearly continuous deposition in this field throughout the Cambrian period, for though the middle Cambrian has not been identified south of Braintree, it lies within the same geological province. The change from the mud of middle Cambrian times to sandy bottoms of upper Cambrian times in this portion of New England apparently indicates progressive shoaling and uplift of the sea floor.

Since the above account was written, Walcott[1] has published a careful revision of the fauna of these fossiliferous pebbles, referring the forms to *Obolus* (*Lingulobulus*) *affinis* Billings and *O.* (*L.*) *spissus* Billings, and to a new species *Obolus* (*Lingulella*) *rogersi*. Walcott suggests the derivation of the fragments from an area of erosion lying in the vicinity of Newfoundland.

SILURIAN PERIOD.

There are no known clastic rocks of Silurian age in situ in this basin. Certain terranes in the southern and western parts of the area formerly referred to this period are now regarded as either Cambrian or Carboniferous.

CHERT PEBBLES.

The possible former existence of a Silurian formation in this portion of the coast is indicated by the occurrence of chert pebbles carrying upper Silurian corals in the Miocene gravels—the "osseous conglomerate" of Hitchcock—at Gay Head and elsewhere on Marthas Vineyard. I am indebted to Mr. C. D. Walcott for the determination of the age of these chert pebbles.[2] Their origin is involved in the same mystery which surrounds the upper Cambrian pebbles.

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[1] Note on the brachiopod fauna of the quartzitic pebbles of the Carboniferous conglomerates of the Narragansett Basin, Rhode Island, by C. D. Walcott: Am. Jour. Sci., 4th series, Vol. VI, 1898, pp. 327-328.

[2] In an early notice of them, based on scanty material, I mistook the single coral then found for a Cambrian form. Am. Geologist, Vol. IX, 1892, pp. 243-247.

CHAPTER III.

THE IGNEOUS ROCKS OF THE BORDER OF THE BASIN.

GRANITIC ROCKS.

The granitic rocks which border this basin from Wrentham eastward and thence along the margin in Plymouth County southward and westward to Fall River are designated Archean on the most recent maps. The rocks are mainly hornblendic granitites.[1] The opinions which have been published regarding the origin and time of eruption of these rocks are various and often contradictory. Edward Hitchcock, if he can be said to have held a definite opinion upon the subject, was inclined to represent the granitic masses as erupted after the Carboniferous formations were deposited. In 1882 Wadsworth clearly showed that the hornblendic granitites in Braintree are erupted through slates now known to be of middle Cambrian age. The granitite of that locality is then more recent than the middle Cambrian. Except for a few detached areas, all around the border of this part of the basin the granitite extends beneath the Carboniferous basal beds, which are in large part made up of the little-worn waste from the granitite. At no point in the northern half of the field has true granite been found in eruptive contact with Carboniferous sediments.

The coarsely crystalline texture of the granitite along most of the margin indicates, according to the accepted opinion, that the rock which is now exposed at surface crystallized at a depth and under a cover of some thickness, probably in part of sedimentary rocks removed from this portion of the area before Carboniferous deposition set in. Some of the Cambrian formations undoubtedly formed part of this cover. No small depth of the granitite must likewise have been carried away. At Braintree the zone of granitite with a finer texture, due to the more rapid cooling near contact with the slates, is preserved, and gives a minimum thickness of several scores of feet between the contact and the inner coarsely crystalline rock.

Although the several varieties of granitic rocks in the area named are

[1] The "syenite" of Edward Hitchcock and earlier writers.

essentially coterminous, these variations are of sufficient extent to be indicated when the mapping of their areas is undertaken. All about the northern margin, particularly near the Norfolk County Basin, where the red Carboniferous sediments abound, the feldspar of the granitite is in many localities of a deep-red color. The association of these red feldspars with the red Carboniferous rocks along this northern border of the field may be without significance, but the relation is noteworthy. The coloration of the feldspar, however, has arisen apparently through the penetration of an iron oxide in solution, following upon atmospheric decay. The oxidation of the iron-bearing silicates in the granitite, e. g., the biotite and the hornblende, may have furnished the iron, in which case there is no reason for supposing that the coloring matter has leached downward from the formerly overlying red Carboniferous beds. On the contrary, it is more probable that the red beds owe their color to this iron oxide having been set free in pre-Carboniferous times. The surface exposures of this red granitite are simply the underlying base of the zone of decayed rock which was swept off in the making of the Carboniferous sediments. The objection which may be raised to this view is that the granitite has been at least twice exposed to atmospheric decay, once in pre-Carboniferous times, and again in recent geological times, and that the red color of the feldspars to-day may be due to recent rather than to ancient decay. But the arkose at the base of the Carboniferous is sufficient proof of the ancient period of atmospheric decay, and the immediately overlying red beds show that the process of rock discoloration by percolating iron oxides went on in early Carboniferous time essentially in the manner advocated by Russell.

The possibility of the coloration of sediments, at least locally, by this means is attested by observations which were made during the present survey. At one point in the region of red granitite I was struck with the redness of the water standing in the bottom of a small test quarry, and with the film of red mud deposited everywhere beneath the water level. There can be no doubt, therefore, that the red granitites are at the present time capable of staining sediments with a red iron oxide film. This process seems to be a local instance contrary to the general yellowish and brownish hues so widely noted as the result of decomposition of rocks in this latitude.[1]

[1] W. O. Crosby, Am. Geologist, Vol. VIII, 1891, pp. 72–82.

Near Easton the glacial drift from the granitite area carries a variety of the rock of bluish-white color with large crystals of hornblende and prismatic crystals of ægirine. At a few points the rock becomes fine grained and is in contact with undetermined rocks, presumably pre-Carboniferous clastics. Such contacts may be observed north of Mansfield and near Hanover Four Corners. In Montello, north of Brockton, the granitite with a pink feldspar was seen to contain small veins of prehnite.

Along the eastern border of the basin, in Plympton, there also is a fine-grained granitite. Southward, in the northern part of the area represented on the Fall River sheet, red granitite is again seen in bowlders, and the ordinary phase of the hornblendic granitite is well exposed in the quarries at Fall River, though here the rock has been locally sheared and in zones is quite gneissoid.

In conclusion, it can not be said that the facts at hand warrant a more definite statement than that these granitites were erupted at some period between the Carboniferous and the middle Cambrian. The granitic rocks near Providence appear, as shown on page 105, to be older.

PLYMPTON FELSITES.

In Plympton and extending toward Halifax is a small area of reddish and greenish felsites, the exact limits of which are not known. At one point on the eastern border of the Carboniferous area the felsite in the form of a dike several feet wide may be seen cutting the granitite. North of this locality is the main occurrence, in the form of a flow, the bands of which dip gently westward toward the Carboniferous basin. As no Carboniferous strata are seen in connection with the igneous rocks at this point, their age is not definitely known. The imperfect exposures seem at least to indicate that the felsite broke through the granitite, and the absence of Carboniferous rocks at the locality, taken in connection with the fact that the supposed boundary of the basin passes through this locality, may be interpreted to mean that the felsite flowed out upon the surface of the granitite at the beginning of Carboniferous deposition. This conclusion is supported by facts set forth on page 155 concerning the felsites of North Attleboro.

GRANITE-PORPHYRY.

Granite-porphyry occurs in the northwestern margin, about Diamond Hill and half a mile northwest of Arnolds Mills.

This latter area affords a tolerably fresh rock, characterized by the presence of large grains of quartz and orthoclase, with microscopic garnet as a rare accompaniment. The quartz occurs in rounded and angular grains. The angulation of the quartz is probably in part due to a movement of the magma after partial cooling. The quartz also shows embayments of the groundmass. It is further characterized by the usually observed fluid inclusions, with gas bubbles, which move about in the cavities. Some of these bubbles simply change their position with reference to gravity when the slide is turned up or down; others keep up a continual oscillatory movement, which is independent of the accidental jarrings due to the manipulation of the stage of the microscope. Magnetite or ilmenite is present. Apparently the iron ores of the granite-porphyries of this district tend to form aggregates having the external grouping of dendritic minerals. Chlorite is present in the groundmass, as are also small crystals of hornblende. Garnet occurs in isotropic sections with a triangular outline, a pinkish tinge in plain light, and with traces of cleavages. Concerning the interpretation of these porphyry stocks, see page 155.

OTHER ROCKS.

Farther south are bosses of hornblende rock which break through the Blackstone series This is a fine-grained, dark-blue rock, evidently of igneous origin. Under the microscope it shows considerable alteration. Hornblende occurs in idiomorphic crystals, affording basal sections. There is a great deal of what appears to be secondary hornblende, shown by its lack of crystalline outline. Chlorite is abundantly present in scaly, felty aggregates. Muscovite exists, probably as an alteration product of one of the original feldspars. Calcite occurs in the rock, and is probably derived from a lime-soda feldspar. The idiomorphic character of the hornblende crystals, where this character is preserved, the nature of the secondary products, and the fact that quartz is present, probably as a secondary product, lead to the opinion that this rock was originally a diorite characterized by little or no free quartz, the quartz now visible having been derived by the breaking up of the bisilicates.

Diamond Hill is a mass of quartz veins probably segregated as late as the period of the Wamsutta formation of the northern border. The quartz, as shown by Dr. Foerste's studies, is mainly developed in the southern part of a mass of granite-porphyry having a superficial extension of about 2 square miles.

GABBRO HILLS OF SHARON.

An elongated lenticular area of gabbro with diorite occurs in the Wrentham-Hingham granitic uplift, bordering the southern side of the Norfolk County Basin. The following notes are from a description of the rock by Messrs. J. R. Finlay and H. I. Richmond, jr., to whom I am indebted for the use of their manuscript report:

From North Foxboro to Canton Junction there is a heretofore undescribed range of hills composed almost entirely of gabbro. The area of this rock is 7 miles long and its greatest breadth about 2 miles. The highest point of this range is Moose Hill, which attains an elevation of 560 feet. Southwest of Foxboro the gabbro extends in disconnected bosses as far as Wrentham.

At Foxboro, Mansfield, East Foxboro, and Canton there are large ledges of coarse, light-colored, hornblendic granitite, so situated as practically to surround the gabbro on at least three sides. In the gabbro and along the northern side are frequent dikes of aplite. The outcrops of a fine-grained granitite along the northern side attain considerable size. Exactly what is the relation of this fine-grained granitite to the coarser granitite which covers so much territory to the southeast can not be determined in the field, as they are nowhere in contact.

The coarse-grained granitite is found in several places, as, for instance, just west of Canton Junction, penetrating in an intricate manner patches of crystalline schist. In the railroad cut just north of the station at Canton Junction there is a large exposure of coarse-grained hornblendic granitite, while south of the station and just east of the gabbro is a large area of biotite-granitite. Adjoining these rocks to the south and east is the light-colored coarse granitite of the region. South of Canton Junction, a mile east of the railroad, there is a large boss of diorite which has burst through the granitite. Blocks of coarse-grained granitite are inclosed in the diorite. Between the diorite and the gabbro is a strip of granitite a quarter of a mile wide.

The coarse granitites are older than the diorite, but are younger than the schists at Canton Junction. The gabbro is older than the fine-grained granitite dikes penetrating its mass, but their relation to the coarse granitites is unknown. The youngest rock of the region is a diabase, which is found in dikes cutting the other rocks.

A petrographical study of the gabbro showed variations to a dioritic phase. The diorite exists in certain areas in the gabbro.

CHAPTER IV.

THE CARBONIFEROUS BASIN.

The rocks referred to the Carboniferous period in the Narragansett Basin are grouped together, either for the reason that they are known to contain the fossils peculiar to this period or because they are stratigraphically united with those which are thus fossiliferous. The members of the formation are arkoses, conglomerates, sandstones, shales, and coals, with a great variety of secondary structures. The strata are almost everywhere bent into steep-sided folds. Limestones and rocks of igneous origin are conspicuous only in certain parts of the area. The beds are nonmarine, and present no signs of equivalency in their lower strata with the lower Carboniferous or Mississippian series.

In a general way the strata of the basin exist under two phases: One is a belt of much metamorphism, beginning near Pawtucket and extending southward and widening to the sea in Narragansett Bay, but most pronounced along the western boundary (see fig. 6, p. 120). The second phase is characteristic of the greater portion of the remainder of the area, or about two-thirds of the whole, extending eastward and north into the Norfolk County Basin. In this field the effects of metamorphism are rarely so great as seem commonly to be believed by geologists. The transition between the two fields is often very abrupt. The geologist who should pass from the nearly vertical metamorphic strata of the East Side in the city of Providence, Rhode Island, to the slightly folded and unaltered sandstone and shale beds of East Providence, would, from a comparison of the rocks alone, be led to infer that there was in this field a set of very ancient tilted rocks flanked on the east by strata of much less antiquity. So short is the space between the two rock phases at this point, being the width of the Seekonk River only, that one is led to believe that an intermediate zone of considerable width has been concealed by a fault.

In the less metamorphosed area, with which this part of the report has

mainly to do, the acquisition of secondary characters in the strata is very closely related to the degree of tilting which they have undergone. Aside from one or two narrow belts of dynamic metamorphism, accompanied by the development of new minerals, the alteration is generally limited to the production of cleavages and joint structures. It is on account of this lesser degree of alteration and the identifiable condition of plant remains that

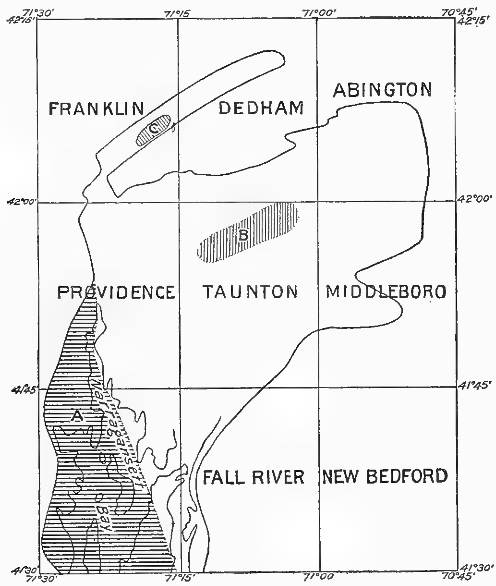


Fig. 6.—Map showing distribution of metamorphosed Carboniferous rocks. A, Narragansett Bay area of maximum metamorphism; B, Winnecconnet area; C, Morrill's area in Norfolk County Basin.

this portion of the field affords the best ground in the Carboniferous basin for determining the succession.

In the subsequent pages the attempt to establish certain rock groups in a typical area will be followed by a description of the extension of the rocks over the remaining field. Before describing the rocks, however, I shall discuss the facts relating to the general structure and the boundary of the basin.

GENERAL STRUCTURE OF THE BASIN.

The broader secondary features of the basin—the system of folds with their axes and the parallel direction of the borders—are relatively simple. The structural outline of the basin is that of a ship's knee, with the angle on the northwest, one arm extending southward to the mouth of Narragansett Bay, the other eastward toward Cape Cod Bay, and the inner curve forming the border from Tiverton northeastward to Lakeville. If a line be drawn from the northwestern corner near Diamond Hill (see fig. 7) southeastward to a bisection of the curvilinear border near Fall River, it will pass through the three deep synclinal depressions in which the uppermost conglomerates of the Carboniferous have been infolded and preserved from denudation. On the northwest this line also passes through the small area of profound dislocation and uplift which brings the granitite of Hoppin Hill, the Cambrian, and the lower Carboniferous strata to the surface. West of this line the strikes trend nearly north and south; east of the line they trend about east and west. This axis of pressure, moreover, appears to have been that in

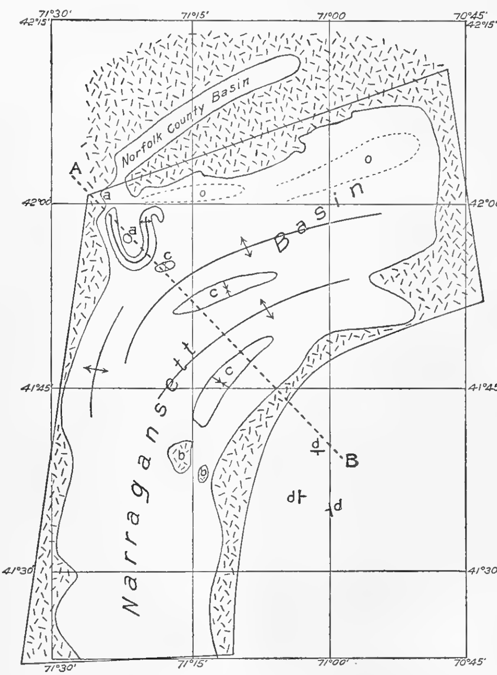
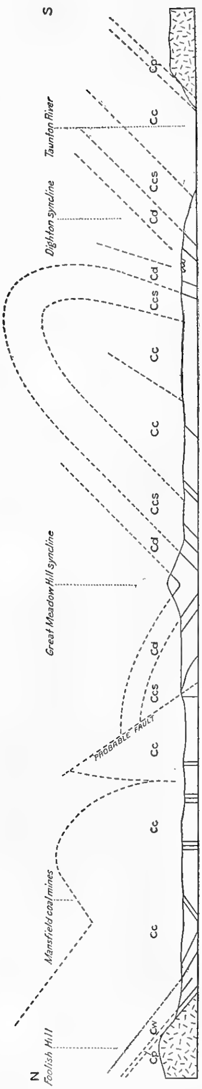


FIG. 7.—Map showing general outline of the Narragansett Basin. A–B, line passing through deeper synclines of middle of the area; aa, inlier of granitite and Cambrian at Hoppin Hill and the Diamond Hill quartz mass on western border; bb, granitic and gneissic inliers near Bristol, Rhode Island; cc, synclines with coarse conglomerates; oo, synclines along northern border of the basin; dd, gneiss structure in New Bedford area.



Horizontal scale: 1 inch = 2 miles

FIG. 8.—Section across eastern arm of the basin. (For explanation of letters see table, p. 134.)

which powerful thrusts have acted on the region to the southeastward. The granitite of the southern border in the region of this axis, notably about Fall River, is sheared and rendered locally schistose by reason of the pressure to which it has been subjected.

If we continue this line still farther southeastward, it will be observed that the gneisses of the New Bedford area exhibit structures roughly concentric to the Carboniferous strikes on the northwest (see dd, fig. 7). The whole array of structures points to an older land mass, now submerged, which lies in this southeastern versant of the New England coast. From this area the deposits of later times, wrapped about its northern and western sides, appear to have been pressed toward the northwest.

The southern arm of the basin is parallel in structure with the strikes of southern New England westward to the Taconic range. The eastern arm of the basin coincides in trend with the Norfolk County and Boston basins in their eastern parts. These last-named show also, in their inner western extensions, the tendency to become concentric with reference to a point on the southeast.

The number of great folds in the basin is few (see figs. 8 and 9). Along the line above referred to there are probably not more than four great synclines and three intervening anticlines. None of these folds appear on earlier sections of this basin (see fig. 10). The great mass of sediments is here thrown into folds having dimensions quite equal to those of the Appalachian folds in Pennsylvania (see fig. 8). From axis to axis of the same kind is a distance upward of 6 miles (see map, fig. 7). With dips often of 45° or more, folds of so great a breadth are commensurable only with a great thickness of

strata, of which there can not be less than 12,000 feet now remaining. East of this line the upper strata are apparently denuded and the structure

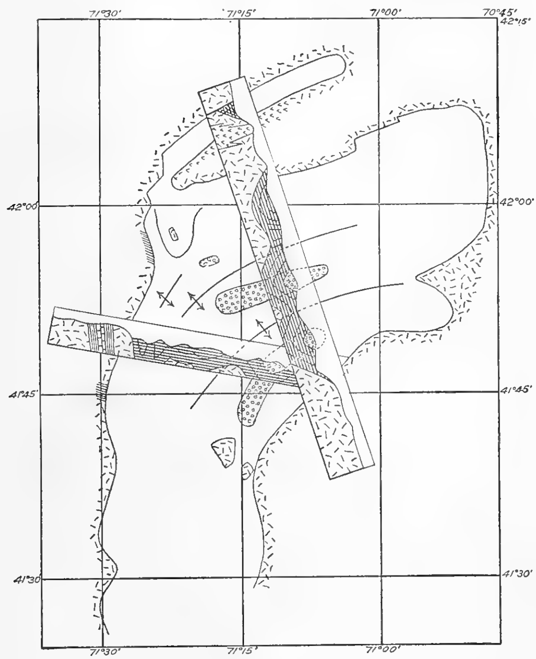


FIG. 9.—Outline map and general cross section of the basin.

is less well shown (see fig. 8), largely owing to the covering of glacial drift. In the southern arm, as is shown in Dr. Foerste's report, like

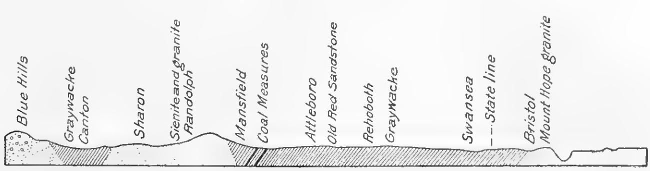


FIG. 10.—Edward Hitchcock's cross section of the Carboniferous area (1841).

changes have taken place, and the incursion of the sea has done that which is performed by sheets of sand and gravel in other parts of the basin.

MAPS OF THE BOUNDARY OF THE BASIN.

The progress in knowledge of the geology of this district is very well represented by the delineation of the boundaries of the Carboniferous formation on maps since the time of Maclure. In his map of 1817 this field of rocks, then called "Transition," is represented as a triangular area, with the base on the eastern shore of Narragansett Bay, between Providence and Westport Harbor, and the apex at Boston.

The first official surveys, those of Hitchcock in Massachusetts and Jackson in Rhode Island, the final maps of which were published in 1841 and 1840, respectively, gave the boundaries as they have been commonly represented on compiled maps up to the present time. Dr. C. T. Jackson's map of 1840 represents the boundary in Rhode Island with much accuracy, but a strip of the more highly metamorphosed beds, in Cumberland on the north and in Kingston, South Kingston, and the southern part of Jamestown on the south, is included in his group of "primary rocks," as are also the basal members of the Carboniferous along the Fall River shore.

Edward Hitchcock's map of 1841 gives the outlying boundary of the Carboniferous with much fidelity, but the shoulder angles, probably due to cross faults, along the northern border are not shown. Owing to his belief in the Devonian age of the red strata in the northwestern part of the field, an attempt was made to draw a line between these beds and the Coal Measures. No attempt is made to show the inliers of granitic and other rocks in North Attleboro and Namasket; indeed, they are nowhere described by him.

A later map, entitled Bristol and Rhode Island Coal Field, published in 1853,[1] represents Devonian rocks as lying in a belt along the western border of the basin from Cranston northward into the Norfolk County Basin, and as sending out branches near Burnt Swamp Corner eastward along the northern border of the main basin to Foxboro and westward toward Bellingham. The occurrence of the Carboniferous formation along the Fall River shore is not yet recognized, nor are the outcrops of granite at Namasket and North Attleboro. The same is true of the horseshoe fold of the red rocks which occur in North Attleboro.

[1] Massachusetts House Document No. 39, March, 1853.

Sir Charles Lyell's map of 1845 is fairly accurate as regards the boundaries of the basin, but the southern half of the Massachusetts extension of the Carboniferous is erroneously colored to represent the Old Red sandstone, or Devonian. The connection with the Norfolk County Basin is not shown.[1]

Sir W. E. Logan, in the geological map of Canada, dated 1864, accompanying the Atlas of 1865, represents, on the authority of James Hall, the outlines of the Carboniferous basin and its connection with the Norfolk County Basin, the beds of which latter field are for the first time colored as Carboniferous.

C. H. Hitchcock published a map in 1871 in which a barrier of granitic rocks between the red beds of the Narragansett Basin and the Norfolk Basin is again erroneously introduced. Other changes in the western boundary are made by referring a belt of strata to the Silurian.

W. O. Crosby's map of 1877 gives a generalized boundary of the northern part of the basin, and an attempt is made to show the connection between the Narragansett and Norfolk County basins. The Carboniferous is shown extending as a tongue northward to Norwood in the Norfolk County Basin, the underlying beds being, on the authority of Edward Hitchcock, represented as Devonian.

In 1880 Crosby and Barton published an account of their tracing the beds of the Norfolk County Basin into the Narragansett Basin, and stated their reasons for considering all the beds to be Carboniferous, but they did not publish a map.

The latest compiled general geological maps of the United States[2] perpetuate the error in regard to the nature of the connection between the Norfolk and Narragansett basins, a bond which was correctly shown on Logan and Hall's map of 1864, and still earlier under the coloring of Devonian in the Hitchcock map of 1841.

BOUNDARY OF THE BASIN ON THE NORTH AND EAST.

From Cranston to the Blackstone River.—In the southwest corner of the Providence quadrangle the basal beds of the Carboniferous are seen standing in nearly vertical attitude against the boundary wall of the pre-Carboniferous series.

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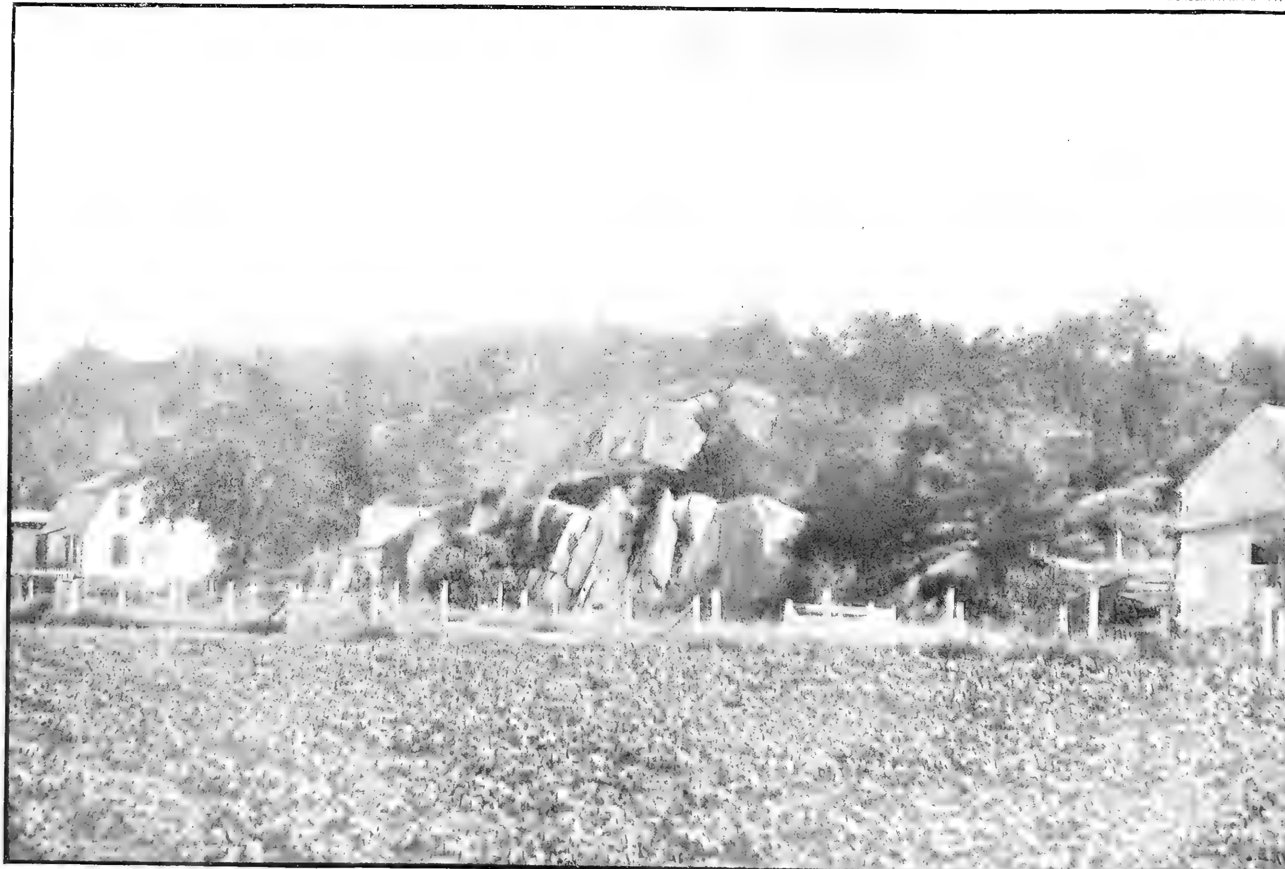
[1] Travels in North America, Vol. II, New York, 1845, Pl. II.

[2] C. R. Van Hise, after McGee and Hitchcock: Bull. U. S. Geol. Survey No. 86, Pl. XI. W. J. McGee: Fifth Ann. Rept. U. S. Geol. Survey, 1884, Pl. II.

The angular fragments of the pre-Carboniferous rocks contained in these beds, together with the meridional strikes of the Carboniferous as contrasted with the nearly east-west strikes of the older clastic series, afford abundant evidence of the unconformity. The exact contact is not shown. North of this locality the Carboniferous beds do not appear clinging to the escarpment above the level of the glacial sand plains. In succession along this escarpment, granite, gneiss, schists, and quartzite come up to the plane of the base of the Carboniferous, indicating the varied lithological character and structure of the floor on which the sediments were laid down along this western border. Direct evidence of faulting is wanting. For most of the distance the lowest and nearest visible outcrops of the Carboniferous are from 2,000 to 3,000 feet eastward of the line, and probably at approximately that distance above the base of the series. Throughout this section a distinct valley exists along the contact; its western wall is formed by the escarpment of pre-Carboniferous rocks, including some Carboniferous beds lying to the west and forming a part of the escarpment at the point of beginning;[1] its eastern wall is formed by a broken ridge of hard sandstones which stand up to the level of the adjacent peneplain developed on the crystalline area to the westward. This ridge is broken through at Cranston and Olneyville; and in each case the gap is opposite a valley opening eastward out of the crystalline area. The deep reentrants in the pre-Carboniferous rocks are thus shown to be of a date later than the Carboniferous period and in no way affect the boundary line by their having been originally filled with sediments. On the assumption that the peneplain is of Jura-Cretaceous age, the denudation of the Carboniferous soft rocks below that level is an index of Eocene and later erosion, and these valleys along and across the contact are post-Cretaceous. The cross valleys are not of glacial origin; the movement of the ice was nearly at right angles to their course. The same remarks concerning the age of topographic features apply to the valley of the Blackstone, the course of which is elsewhere described in this report. It suffices to state here that it turns from a southeast to a south course immediately on entering the basin.

[1] In tracing the boundaries of the rocks lying on the western boundary of the Narragansett Basin, Mr. J. H. Perry, of the United States Geological Survey, has recently shown that metamorphic Carboniferous arkoses and conglomerates occupy a small area, about half a mile wide, lying to the west of the boundary as drawn by Dr. Foerste and myself where our maps join.



PRE-CARBONIFEROUS ROCKS AT WESTERN BORDER OF BASIN, NEAR PROVIDENCE, RHODE ISLAND

From the Blackstone River to Sheldonville.—Throughout this northern half of the western boundary actual contacts of the Carboniferous upon the underlying rocks have not been seen. North of the Blackstone River the NW.-SE. strikes of the Blackstone series can be traced to within short distances of the NE.-SW. strikes of the Carboniferous beds, indicating from the angle which the latter make with the western boundary that they have probably been faulted. From Millers River northward a boundary valley continues as far as Diamond Hill. In the Millers River section gray basal conglomerates dip off eastward at steep angles, but the valley is wholly excavated in the Carboniferous rocks. Northward, in the Thompsons Hill area, the Coal Measures come in, apparently by downfaulting along the border. From Diamond Hill to Joes Rock, seen on the Franklin atlas sheet, the Carboniferous rocks are in unconformable relation with the lower Cambrian red shales, but details of this relation are wanting.

Connection between the Narragansett and Norfolk County basins.—At Sheldonville the rock of the Narragansett Basin can be traced, as stated by Crosby and Barton in 1880, into the southwestern end of the Norfolk County Basin, through a pass not exceeding 2,500 feet in width between walls of the hornblende-granitite. The hornblende-granitite comes up to this stratigraphic isthmus with nearly rectangular corners, as shown in the map, fig. 7 (p. 121).[1]

Sheldonville cross fault.—The most reasonable explanation of the rectangular boundaries of the Carboniferous and granitic rocks at this point is, as suggested by Mr. J. R. Finlay, the occurrence of a fault passing in a NNW.-SSE. direction. This view is confirmed by the extensive faulting of the Carboniferous beds southward through Plainville in the same direction, as Mr. Finlay has amply demonstrated in the field.

Actual fault contacts in the Sheldonville pass have not been seen. There is an outcrop of red sandstone striking NE. and dipping 60° N. in the pass in the western granitic corner, very close to the supposed fracture.

From Sheldonville to Foolish Hill.—From near Burnt Swamp Corner eastward the boundary can be fixed with approximate exactness. Messrs. L. S. Griswold and C. F. Marbut have determined the relations of the rocks at a number

[1] Some of the earlier geologists supposed that the Rhode Island and Worcester areas are connected through the Blackstone Valley, but Prof. Edward Hitchcock showed that these areas are separated by a wide district of gneiss. Dana, Manual of Geology, 3d ed., 1880, p. 319. Hitchcock, Final Report on Geology of Massachusetts, 1841.

of points as far east as Brockton. The basal series of the Carboniferous may be seen within a few feet of contact with the granitite in Wrentham, in the low hill half a mile north of the Shepardville reservoir. So far as can be observed, the strata are simply downfolded without faulting. Along this line there is little topographic expression to the contact. The Carboniferous area is covered by a low, gently undulating drift plain, while the granitic rocks rise into rounded knobs having elevations of from 100 to 200 feet above the plain on the south.

Foolish Hill fault.—Midway between Foxboro and Mansfield the boundary line makes a rectangular turn along the western face of Foolish Hill. This side of the hill presents a long, smooth wall, inclined steeply westward. The basal beds of the Carboniferous rise up on the southern face of this granitic hill, with steep dips to the southward, and reappear on the low ground to the westward with an offset of 2,000 feet or more to the north. The railroad from Mansfield to Foxboro follows approximately the line of this fault.

From Foolish Hill to Brockton.—Eastward to Easton the contact can be traced with less certainty. The attitude of the basal Carboniferous beds on the south varies as regards angle of dip from point to point, but is generally much steeper as the contact is approached. This change of dip is so marked in some cases as to suggest unconformity between the red basal series and the overlying gray carbonaceous beds. While, as before noted, no actual faulting can be shown in these cases, it may be questioned whether the steeper dips along the border do not express the upward drag of the edges of strata from downfaulting of the rocks in the basin.

Between Easton and Brockton there are positive indications of small faults along the boundary, shown in actual exposures, but the precise nature of the disturbances and their bearing upon the form of the basin in this region are not clear on account of the drift coating.

A mile northeast of the last-named locality is a very considerable irregularity in the boundary, by which, according to Messrs. Griswold and Marbut, the red beds in vertical positions are let into the granitite floor. Still nearer Brockton the sudden disappearance of red sandstone in the drift for a space indicates a displacement or disappearance of the beds by erosion. The fact is worth noting here that the coarse pink granite just south of Montello railroad station is faulted along NE.-SW. planes.

In the course of grading the bed of the Old Colony Railroad from Brockton northward, since the field work for this report was finished, Carboniferous gray sandstones with fossil plant stems were exposed, according to the studies of Mr. M. L. Fuller,[1] for some distance north of the main boundary line on either side of that city. I am indebted to Mr. Fuller for information concerning the boundary as drawn on the accompanying map.

From Brockton to North River.—Outcrops of the stratified rocks here become very infrequent, but enough are exposed to define the approximate position of the boundary.

Shumatuscacant fault.—Between Brockton and Abington there are angles in the border which indicate the existence of cross faults, one in the path of Beaver Brook, the other, and more unmistakable case, that along the line of the Shumatuscacant River in Abington. By this latter dislocation the boundary line on the east is set northward for the distance of a mile.

Through Rockland and thence eastward across Hanover to the northeast corner of the basin, the boundary can be delineated only by drawing a line south of the known exposures of granite and north of the first appearance of Carboniferous rocks in the drift. The valley of Third Herring Brook follows the boundary for a short distance, and the North River takes an eastward turn across the line.

From North River to Lakeville.—Along this line the boundary is, because of the drift mantle, not accurately known. Granitite appears in Namasket about 4 miles west of the line, as heretofore represented on maps of the basin, and it is not certain that this outcrop is a mere inlier. In the absence of positive information on this point it is tentatively represented as a part of the eastern granitic area. Between North Plympton and Halifax the basin is also made to include an area of felsites, the exact limits of which are unknown. The protrusions of the eastern margin into the basin in the form of felsite in Plympton and of granitite in Middleboro are near enough to the lines of anticlinal axes in this portion of the basin to lend support to the hypothesis that the basement of the Carboniferous is exposed at these localities by the folding of that floor in conformation to the structure of the once overlying strata. If this view be correct, we should expect to find the lobate areas between the tongues of igneous rock forming synclines in the

[1] A new occurrence of Carboniferous fossils in the Narragansett Basin: Proc. Boston Soc. Nat. Hist., Vol. XXVII, 1896, pp. 195–199.

Carboniferous. The single but pronounced meridional strike of the outcrop near Judson post-office proves that the Great Meadow Hill syncline does not extend to the eastern margin, and we are led, therefore, to infer that other synclines exist in this heavily drift-covered region. The east-west strikes of the Carboniferous in Hanover, where they are in close proximity to the border running north and south, make it almost necessary to suppose that there has been faulting along this line. Granite of a euritic texture occurs south of Plympton, setting an eastern limit to the Carboniferous, and there is thus no evidence to show that the Carboniferous extends toward Cape Cod Bay east of the line drawn on the map.

In the Furnace Pond area reliance has been placed upon the distribution of the glacial drift, the incoming of granitic blocks in large quantities being taken as the approximate northern position of the granitite on the south of the basin. The line across the lakes, in Lakeville, is wholly conjectural, but is confirmed by the position of granitite exposures three-fourths of a mile southwest of Elders Pond.

From Lakeville to Steep Brook.—From the vicinity of Myricks southwestward the contact begins to take on a topographic expression and is marked by an ice-worn granitic escarpment, at the foot of which runs the Assonet River. Just south of Myricks the valley of Swamp River breaks through the granitite and is taken advantage of by the New Bedford branch of the Old Colony Railroad. In Freetown the granitite is exposed in Washington Mountain and near Break Neck Hill. Finally, at Steep Brook, seen on the Fall River sheet, the basal arkoses and conglomerates are found resting on the granitite and dipping off northwestward at an angle of 45°.

INLIERS.

In addition to the facts regarding the outlying boundary of the Carboniferous, a few statements may be made concerning the contact of the formation with the inliers which have been noted in this portion of the basin. Inliers are conspicuous features on Newport Neck, Conanicut Island, and in the region about Bristol, for a description of which the reader is referred to Dr. Foerste's section of this report.

There is only one definitely determined inlier in this northern part of the basin—that of Hoppin Hill, in North Attleboro—though it is possible that there are others, as at Namasket and in the Cambrian locality near Diamond Hill.

North Attleboro inlier.—In the North Attleboro inlier (see Pl. XXIX, in Part III), actual contacts of the Carboniferous with the subjacent Cambrian and granitite are not exposed, but the evidence points to the unconformable relation of the Carboniferous and Cambrian strata.

Namasket granitite area.—Hornblende-granitite, similar to the rock of the northern border of the basin, appears in a low outcrop about 60 feet above the sea in the village of Namasket, in the town of Middleboro. The exposure by the roadside is upward of 200 feet in length, and is at a distance of $3\frac{1}{2}$ miles from the nearest granitite outcrops to the southeastward. The nearest visible stratified rocks are 2 miles south, and nothing is known regarding the contact. It is not at all improbable, as above stated, that the exposure of granitite at this point marks an anticlinal structure in the Carboniferous by which a tongue of the granitite protrudes into the basin from the eastern border, as does the long, broad area from Hingham westward to Sheldonville, separating the Narragansett from the Norfolk County Basin.

SUMMARY.

The boundary in this northern part of the field appears to be mainly one of downfolded beds where the line extends east and west. Downfaulting is suggested only where the line runs north and south. Correlated with this evidence is the presence of arkose along the east-west borders, and its almost complete absence along north-south lines in the upper part of the basin. These faults are parts of a series which appear on the east-west boundary lines as cross faults.

The type of fault crossing the boundary of the basin is repeated a number of times along the northern border. These cross faults along the northern margin do not clearly arise out of the physical conditions engendered at the contact of two terranes so unequally acted upon by stress, but rather they are regional dislocations arising in the pre-Carboniferous terrane, their existence being clearly brought out by the rectangular notches which they introduce into the boundary line. Outcrops are wanting to show how far these faults affect the beds in the basin above the lowermost strata. Even if the faults were limited to the granitite and the beds immediately at the base, we should expect to find a local deflection of the strike, in the form of a flexure, in the direction of the offset at some distance beyond the margin of the fault plane.

It is to be noted that the faults along this border are of the normal Basin Range type, the downthrow being in blocks on the east and west of a relatively uplifted block in Easton. The northward recession of the boundary east and west of this block is in accordance with this structure. The system of faults is, moreover, transverse to the Wrentham-Hingham uplift of igneous rocks. So far, however, these fractures have not been traced into the Norfolk County Basin. The throw of these faults is not necessarily great. The dip of the strata near Brockton and Abington is generally low, not exceeding 15°, and the surface is level, so that a vertical downthrow of 1,420 feet would account for the displacement of the boundary 1 mile on a horizontal plane at the latter place.

The date of the faults is not in most instances determinable. They are clearly post-Carboniferous, but their correlation with the dislocations which deformed the Newark basins along the Atlantic coast in middle Mesozoic times has not been proved.

CHAPTER V.

THE CARBONIFEROUS STRATA.

DETERMINATION OF HORIZONS WITHIN THE BASIN.

The earliest attempts to discriminate horizons within the limits of the basin were made by Edward Hitchcock in the northwestern part of the area, where, on lithological grounds, the red Carboniferous beds were referred to the Devonian period.

Sir Charles Lyell, in 1845, mapped as Devonian a broad band of strata extending through Rehoboth, Swansea, Taunton, and thence to the eastern margin, but it is now known that the beds so mapped are Carboniferous. In 1871, C. H. Hitchcock mapped a small area in the southwestern part of Attleboro as belonging to the "Quebec group," and a strip along the western border of Rhode Island as Silurian, but both these occurrences are now known to be Carboniferous. In the earlier work of T. Nelson Dale about Newport, the Carboniferous and earlier strata were divided into Paleozoic groups based on lithological characters. Beyond these incomplete maps no attempts have ever been made to exhibit the formations which have been recognized by several authors as forming horizons in the coal basin.

MEANS OF DETERMINING SUPERPOSITION.

The means of determining horizons in the Carboniferous rocks of the Narragansett Basin are purely physical. As yet the fauna and flora of the Carboniferous beds are too little known to be employed. A series of basal arkoses overlain or replaced from point to point by simple quartzose conglomerates can be traced fairly continuously about the margin, and may be recognized at a few points in the interior. Above these is a great succession of conglomerates, sandstones, and shales with coal seams, which are rarely traceable for more than a few miles. The formation is preeminently conglomeratic.

In the main, reliance has been placed on matching strata on opposite sides of anticlinal and synclinal axes, checking these observations by gross measurements of thickness and by observed gradations in texture and thickness of individual beds. The results can be said to be little more than approximations. In portions of the area, particularly in the eastern part of the field, a description of the geology can deal with little more than isolated outcrops.

I am of the opinion that, were the several horizons of shales explored for fossils, a sufficiently differentiated flora would be found on which to base a more satisfactory subdivision of the great middle series of sandstones and shales than is here proposed on purely physical grounds.

Tabular view of the strata in the Narragansett Basin.

Group.	Northern field.		Southern field.		Remarks.
	Local areas.	Characters.	Local areas.	Characters.	
Dighton (Cd) (1,000-1,500 feet).	Rocky Woods conglomerate. Seekonk conglomerate.	Coarse quartzite and granitic pebble conglomerates, with finer conglomerates and sandstone.	Purgatory conglomerate.	Coarse quartzite pebbles, usually much elongated and indented.	Probably, though not certainly, identical in all parts of the field, lying in synclines above the Coal Measures.
Rhode Island Coal Measures (Cc) (10,000 feet).	Westville shales and Seekonk sandstones. Tenmile River beds. Mansfield beds. Cranston beds, Sockanasset sandstones, Pawtucket shales.	Alternations of fine and medium quartz, quartzite, and granitic pebble conglomerates, with pebbly sandstones, sandstones (grauwacke), shales, and coal beds, becoming metamorphic southward. Colors: Black, blue, green, gray, locally red. Odontopteris flora and insect beds.	Aquidneck shales of Dr. Foerste. Kingstown series of Dr. Foerste.	Mainly shales with coal beds. Mainly sandstones and conglomerates with coal shales; usually metamorphic.	Both the Aquidneck and Kingstown series of Dr. Foerste, when traced northward, appear to form equivalent sections beneath the Dighton group, one on the eastern, the other on the western side of Narragansett Bay, and both extend downward to the basal beds in this typical area.
Wamsutta (Cw) (1,000 feet).	Wamsutta slates and shales. Attleboro sandstone. Wamsutta conglomerates.	Beds of quartz, quartzite, felsites, felsite breccias and felsite conglomerates, sandstones, arkose, and shales. Colors: Red, locally brown, and green. Calamites.			The Wamsutta beds are not traceable south of Providence; probably represented by lower strata of Dr. Foerste's Kingstown series. In the vicinity of Pawtucket the Coal Measures underlie the Wamsutta.
Pondville (Cp) (100 feet).	Millers River conglomerates, arkose beds.	Quartz conglomerates. Coarse, white, granitic waste or arkose.	Basa beds.	Quartzose conglomerates and arkose.	Essentially similar products of decayed granitic land surface in all parts of basin.
Uncomformity.	Widespread erosion interval, representing all of Silurian and Devonian time and probably upper Cambrian.				
Pre-Carboniferous.	Broad exposures of granitite intruded into lower and middle Cambrian and pre-Cambrian sediments.		Same as in northern field.		Pre-Carboniferous strata not definitely determined; Cambrian or pre-Cambrian.

FORMATIONS BELOW THE COAL MEASURES.

PONDVILLE GROUP.

BASAL ARKOSE BEDS.

Along the northern border where observations can be made, the red rocks of the Wamsutta series either rest directly on the granitite or are separated from that basement rock by a sheet of grayish arkoses and quartz pebble and quartzite conglomerates. It is evident that the first appearance of red sediments was not simultaneous all along the border, but that it depended upon local conditions, such as the debouchure of streams, the position of headlands or bays controlling the nature of local shore-line deposits. With the exception of the few places where the red sediments designated as members of the Wamsutta series come in at the base, there may be said to exist a horizon of sediments not of red color underlying the Wamsutta and bearing in the nature of their particles, independently of their position, every evidence of being a basal series. These rocks appear not only beneath the red strata in the Narragansett Basin, but also in a characteristic section in the western part of the Norfolk County Basin. I shall refer to the exposures of these basement strata in the few localities where they may be studied to advantage.

Foolish Hill exposures.—At the base of the Carboniferous, on the southern face of Foolish Hill, between Mansfield and Foxboro, basal arkoses are well exposed; but here thin bands of red slate begin to make their appearance, a few feet above the base.

North Attleboro exposures.—In the town of North Attleboro, on Division street, and at points near the railroad station on High street, there are broad exposures of a gray arkose derived from the disintegration of the hornblendic granitite. Similar exposures occur east of the town, where by folding the basal series are brought up in close-pressed folds.

Pierces Pasture in Pondville, Norfolk County Basin.—The clearest exhibition of the basal beds of the Carboniferous is to be found in the Norfolk County Basin near Pondville Station, on the Walpole and Wrentham Railroad. The small area known as "Pierces Pasture" exhibits in its topography much of the ruggedness of an unglaciated region, insomuch that the nearly vertical beds stand out in ridges where hard and resisting, or sink into depressions where soft and yielding. The almost entire absence of glacial drift from the area

is due to its having been covered by a remnant of the ice sheet whose marginal sand plains surround the field on the east, south, and west. The Carboniferous beds rest here upon the granitite and dip off steeply to the north, in the form of a closed and puckered syncline plunging eastward, the cross section of which structure is as follows, beginning on the south:

1. A small knob of hornblendic granitite. This passes by almost insensible gradations into arkose.

2. Alternating beds of arkose and grits, with vein quartz pebbles, occasional nodules of the granitite, and shaly partings.

3. Quartz-pebble conglomerate, with sandstone partings, the latter holding casts and hollows of fossil trees from a few inches to more than a foot in diameter, often closely pressed and forming a mere gash with an ocherous cellular layer. (The fossils described by Crosby and Barton in 1880 were the casts of this locality.)

4. Red and green slates, with sandy partings.

5. Fine quartz-pebble conglomerate in eastern part of the lot; wanting in the western section.

6. Red and green slates, like 4 above, with flattened and cylindrical casts; and small greenish chloritic kernels, due to metamorphism.

7. Quartz-pebble conglomerate, with sandstone partings, containing casts and molds of fossil trees; one cast 12 feet long and 12 by 18 inches in diameter.

Whole section 250 to 300 feet in thickness.

Northward the beds are concealed beneath a swamp. This section is, on the whole, one of the most instructive basal sections in the Carboniferous field of Massachusetts, and may be taken as typical for the general history of the beginning of sedimentation in the main basin.

Absence of basal granitic conglomerates.—It is a noteworthy fact that while the entire Carboniferous section, amounting probably to a thickness exceeding 12,000 feet, is mainly conglomeratic, there is in this northern half of the main basin no widespread basal conglomerate such as we find exactly at the base of many sections in the geological record. The general absence of basal conglomerates and the presence of arkose along the border indicate clearly the condition of the land surface from which the earliest sediments were derived. The failure to produce pebbles of the original rock under the first attack of denudation must evidently have been due to the deep disintegration of the granitic terrane whence the sediments were derived and the low grades of streams. By the disintegration of the feldspar and the decay of the iron-bearing silicates of the igneous rock the crystalline ingredients fell into the state of coarse sand, and in this form the superficial portion of the granitite was removed to the area of deposition. It was only

later, as a result of renewed uplift of the land or of the deeper intrenchment of streams and the incision of waves, that the fresh, undecomposed granitite came into the grasp of the eroding agents, and, breaking up along planes of fracture, made pebbles. In the meantime, there were portions of the granitic terrane which did not disintegrate. These parts were the quartz veins and nodular segregations of quartz in pegmatites, and to some extent, perhaps, in dike rocks, which remained and formed pebbles. It is owing to this reason that the first conglomerates overlying the arkose beds are composed mainly of quartz pebbles. The considerable mass of these pebbles gives some idea of the thickness of the decomposed granite section which was removed at this time. In any section of the neighboring granitites at the present time the volume of quartz large enough to form pebbles in a cubic yard of the rock is relatively very small. Large and thick veins occur here and there, but it is not conceivable that more than 1 per cent of the average granitite mass would yield quartz pebbles. It is evident, therefore, that a very thick section of rock was subjected to disintegration and removal in order to form a bed of quartz conglomerate 50 to 100 feet thick. How much of the quartz came from veins in sedimentary formations into which the granitite doubtless penetrated can not be known. The quartz would probably be more abundant in these rocks than in the granitic stock itself. That the depth of granite removed to form these arkoses and quartz pebbles was great is also indicated by the coarsely crystalline texture of the granitite along the border, showing that the parts which we now see are well into the interior of the original mass and not near the contact with the rocks into which the granitite was intruded, for the reason that at the contact the granitite would have cooled down more quickly and thus have induced upon its crystals a more minute texture than exists in the mass, where cooling went on more slowly.

Geographical conditions indicated by the basal arkose.—The formation of beds of arkose, and the abundant reasons above cited for believing that the land on which the Carboniferous beds were laid down had long been subjected to secular decay and leaching, make it necessary to suppose that the grades of the streams were too low for the removal of the products of disintegration as fast as they were formed. The site of the basin, which appears to have undergone depression at the time deposition set in, must have been previously without very strong contrast with the surrounding country, except

so far as it was a lowland or valley, as Professor Shaler supposes it to have been. That a long period of erosion or nondeposition had closed at this time is abundantly proved by the marked unconformity of the Carboniferous with the underlying terranes, this great stratigraphic break embracing, as above noted, all of Silurian and Devonian time, if not as well the upper Cambrian at the beginning of this interval and the lower Carboniferous at the close.

Absence of iron oxides in the basal arkose.—The prevailing whitish and grayish hues of the basal arkoses, and of the conglomerates immediately above them, are in strong contrast to the often vivid reds of the overlying and occasionally intercalated Wamsutta series to be described beyond. This bleaching of the first Carboniferous sediments appears, like the coloring of the Wamsutta beds, to have taken place prior to transportation, and the two processes may be said to be complementary to each other. The granitites along the northern border, and almost everywhere adjacent to the portions of the basin where the red series of strata occur, are strikingly red by reason of the discoloration of one of their feldspars. This reddening is probably one of the results of alteration through atmospheric decay, but it is difficult to determine when this change in the feldspar began to take place in an effective way, for the granitites in the present superficial zone have at least twice been exposed to meteoric waters, once at the beginning of the Carboniferous deposition, when the shore line was creeping over the rock, and since then when the Carboniferous covering was swept away and the rocks were again bared to weathering. It is hardly possible to suppose that the decay which has led to this reddening occurred in Carboniferous time, for the reason that the pebbles of granitite found in the conglomerates of the red Wamsutta series, or higher up, are, so far as I have observed them, never red except by absorption of the red paste in which they are embedded. The most reasonable supposition which I am able to advance is that the superficial products of weathering previous to their transportation in Carboniferous time were leached of their iron salts, which penetrated downward. The first transportation of detritus affected the superficial leached layer, and thus the basal beds came to be white, as we now see them. When erosion had stripped away the bleached materials at the surface, it reached the highly discolored rock beneath, as yet very imperfectly disintegrated, from which were produced the red beds of the Wamsutta series.

Absence of carbonaceous matter along the northern margin.—Another factor which has given free play to the interchanges of the iron oxides above mentioned in their effect upon the color of the rocks is the very general absence of carbonaceous matter, or coal beds, in the basal series. In proportion to the amount of carbonaceous remains present in the strata, the colors due to the different states of iron are concealed.

Extent of the arkose zone.—There is reason for believing that the arkose bed is nearly continuous about the margin of the basin, and that its disappearance is due to faulting or to original local conditions which prevented its accumulation. To what extent the sheet of arkose extends beneath the basin is not known, as the rock is not exposed in the anticlinal axes in the central part of the basin, for the reason that erosion has not there cut down to the base. The arkose, together with the associated quartz conglomerates, wraps around the tongue of granitite and associated igneous rocks which form the Wrentham-Hingham uplift between the Norfolk and Carboniferous basins, and I see no reason why the Carboniferous basal sediments should not have been continuous over this area, so as to unite the two sets of beds in the present distinct basins. Until it can be shown, as Crosby and Barton believed in 1880, that the arkose and higher strata on either side of this granitic mass were derived from it alone, and not carried over on it as a sheet of sediment from some still more northern area, there seems no reason for accepting the view that this anticlinal ridge rose above the general level in Carboniferous time. There are no general facts to show that the arkose was carried along shore by currents more in one direction than another. If anywhere thicker than at other points, the arkose is probably most developed in North Attleboro. In the eastern part of the basin, and generally in the northern and eastern portions, there are many sandstones far above the base which would be denominated arkose, but they are not to be mistaken for the mixture of quartz and feldspar of granitic aspect which makes up the mass of the basal series. This arkose in some instances differs but little from the original igneous rock whence it was derived, except for the solution of the iron-bearing silicate, a slight trituration of the grains, and the intercalation of clearly stratified beds or occasional waterworn quartz pebbles.

SUPRABASAL CONGLOMERATES.

The conglomerates which occur near the base along the margin of the basin are not precisely basal in the sense in which that word finds its most exact use. At a few points conglomerates actually rest upon the basement floor of granite, but they more usually overlie beds of arkose. The reason for this order of deposits lies in the fact, before noted, that the granitic land area was, in the beginning of Carboniferous erosion and deposition in this field, so decayed at surface that pebble making did not go on until the layer of disintegrated granite was stripped off. It is in full accord with this chemical preparation of the sediments that we find the first conglomerates prevailingly quartzose and composed of quartzite—rocks which do not yield to atmospheric decay so readily as the granite. On account of this sequence in the deposition—first arkose, and then conglomerate—the term *suprabasal* conglomerate expresses more exactly than *basal* conglomerate the nature of the inferior pebble beds in the Narragansett Basin. Of these suprabasal conglomerates there are a few noteworthy exposures believed to be approximately on the same horizon. The beds are often composed of quartz pebbles, the remnants of veins in the granitic border, the latter rock occurring less abundantly than in the higher conglomerates. These beds form the closest analogy to the typical Millstone grit which occurs in the basin, and the following locality, being typical, has been chosen for the type, although the relations to the arkose and the basement rocks are better shown elsewhere.

Millers River conglomerate.—In the valley of Millers River, in Cumberland, Rhode Island, there is a broad exposure of conglomerate beds underlying the red Wamsutta series. In this gray series there are three or four thick beds of conglomerate with small quartz and quartzite pebbles. The best section is exposed on the farm of Mr. James A. Miller. The thickness is here unusually great, being as much as 300 to 400 feet.

South Attleboro exposure.—Between South Attleboro and Lanesville, in the triangular area between the southern end of the great horseshoe fold of the Wamsutta and the Pawtucket area of these rocks, is an exposure of hard quartzose conglomerate, with quartz veins. These beds evidently underlie the Wamsutta, which once arched over them. They are probably continuous with the Millers River outcrops on the northwest, though that

connection can not now be traced. A few bands of red slate occasion their northern upper face

Jenks Park exposure in Pawtucket.—A knob of fine gritty conglomerate occurs in the upper part of Pawtucket just west of the band of red slates belonging to the Wamsutta series, and is, like them, evidently brought to the surface by a fold.

Other exposures of the conglomerate occur along the northern margin, and at various points southward, in the area investigated by Dr. Foerste.

THE WAMSUTTA GROUP.[1]

Devonian or Old Red Sandstone. Edw. Hitchcock: Final Report on the Geology of Massachusetts, 1841. Catalogue of Rocks in Agricultural Museum, Sixth Ann. Rept. Mass. Board of Agric., 1859, Appendix, p. xxvii. Mass. House Doc. No. 39, 1853.

Carboniferous. Logan and Hall: Geological Atlas, 1865.

Devonian and undetermined. C. H. Hitchcock, 1871.

Carboniferous. Crosby and Barton: Am. Jour. Sci., 3d series, Vol. XX, 1880, pp. 416–420.

Cambrian. Shaler and Foerste, 1887. (At North Attleboro.)

Carboniferous. J. B. Woodworth: Am. Jour. Sci., 3d series, Vol. XLVIII, 1894. (At Canton Junction.)

The name Wamsutta series is applied in this report to the red strata a part of which were mapped as Devonian by Edward Hitchcock. The name is used in a geographical and lithological rather than a chronological sense, for it is evident from an examination of the field that these red rocks are local deposits in the northern part of the basin and in the Norfolk County Basin, and are represented by ordinary gray and carbonaceous sediments farther south. An exact correlation with these southern beds is not at present possible. Along the northern margin the red series underlies the Coal Measures. At Pawtucket it is interstratified with them.

The list of references at the head of this section will give the reader an idea of the various opinions held regarding the age of these beds. The typical area in North Attleboro was definitely shown to be of Carboniferous age in 1887 by Dr. Foerste's heretofore unpublished discovery of Carboniferous fossils in the area southwest of Reservoir Pond in North Attleboro.

[1] Wamsutta, a name proposed, but not actually adopted, for North Attleboro. The "Wamsutta Mills" are situated within this town. Wamsutta was the oldest son of Massasoit, chief sachem of Pockanoket, brother and predecessor of King Philip. He was named Alexander Pockanoket by the court at Plymouth, June 10, 1660. The term is used by Dr. Foerste in his thesis on this field, a manuscript report now in the library of Harvard University.

RED ROCK AREAS.

There are eight areas in the northern part of the basin in which reddish rocks have a surface exposure, and in these they are brought to the surface by strong folding. 1. In North Attleboro and the adjoining towns of Wrentham, Massachusetts, and Cumberland, Rhode Island, a large horseshoe-shaped area wrapping about a knob of granitite in Hoppin Hill and the North Attleboro Cambrian outcrops. 2. A small lens-shaped area extending northeastward from Central Falls, Rhode Island, into Massachusetts. 3. A still smaller area south of the last, extending northeastward from the gorge

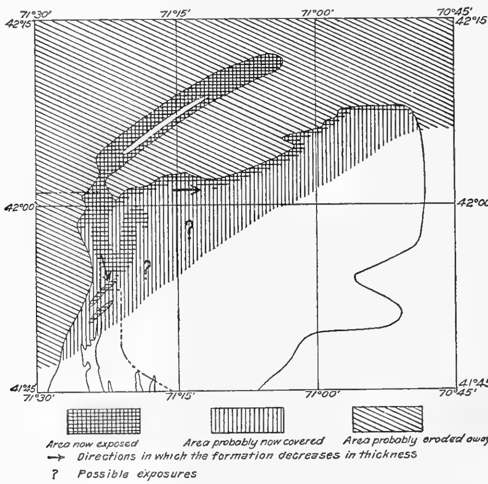


FIG. 11.—Map showing distribution of red sediments.

of the Blackstone in Pawtucket. 4. A characteristic elongate narrow area extending along the northern margin of the main basin and traceable as far as the North River in the town of Hanover. This area is probably connected at the west with the succeeding. 5. The largest area of all, extending from No. 1, near Sheldonville, northward and eastward to Braintree, forming the greater part of the strata in the Norfolk County Basin. There are exposures in (6) Attleboro and (7) Rehoboth, and one in (8) Norton, which may belong to a different horizon. I shall begin the account of these fields with the area along the northern border of the main basin.

THE AREA ALONG THE NORTHERN BORDER.

The area of reddish and chocolate-colored strata along the northern margin of the basin, from near Burnt Swamp Corner eastward, is considered first for the reason that along this line there is indubitable evidence of the relative positions of the red and gray rocks. Throughout the extent of this northern margin the red conglomerates, sandstones, and slates occur at or near the base of the Carboniferous formation, or are separated from it by beds of arkose and gray quartzose conglomerates. The beds can be studied along the border in Wrentham about three-quarters of a mile north of the Shepardville reservoir, in two small hills lying west of the stream which comes in from the north. Immediately south of a small contact valley between the granitite and the Carboniferous beds of the border appear red sandstones and slates. The rock is pervaded by two sets of cleavage planes striking about in the line of the border, the dip of one being nearly vertical and that of the other into the granitic terrane at an angle of 70°. The attitude of the sedimentary beds is not very plainly exhibited. Limited exposures of banding indicate a strike parallel with the border and a southerly dip of from 25° to 30°. The outcrops in the western knoll show red sandstones succeeded by greenish sandstone, which in turn is succeeded by more red sandstone. Near this locality an old millstone made out of a reddish conglomerate with small quartz pebbles was seen in 1894 built into the fence. The greenish sandstones just mentioned have a more extensive development in the North Attleboro area (p. 151).

The red beds are well exposed on the southern face of Foolish Hill in Foxboro. They here dip steeply southward. The cleavage dips steeply northward. Thin bands of red slate may be seen intercalated between beds of whitish arkose. Red conglomerates with quartzite pebbles also occur. The thickness of the beds is difficult to obtain with accuracy, but it may be estimated at this point as upward of 1,000 feet.

Red beds appear to the east near the contact, at some points conglomerates prevailing over sandstones. The thickness evidently diminishes toward the east, but exact measurements are wanting. The red color of the basal rocks also declines and becomes of a chocolate hue. The strata are rarely deep red east of Brockton, though deep-red slates occur northeast of Abington. In the eastern part of the field red conglomerates are no longer recognized.

The relative paucity of granitic pebbles in the Wamsutta conglomerates along the northern border is evidently due to the previously mentioned condition of the granitite at the time deposition set in. Nowhere is there a sharper contrast between the arkose beds and the red shales than on the southern face of Foolish Hill. Bands of red shale here alternate with the arkose in a manner to show that the small particles of the shale brought with them their coloring matter from the seat of denudation, as Russell has argued in the case of the red beds of the Juratrias.[1] The importation of the oxide of iron subsequent to deposition would have colored the arkoses and the shales alike.

About a mile southwest of Whiteville, shown on the Dedham sheet, conglomerates occur dipping gently southward. The quartzite pebbles of this rock are locally brecciated, and their surfaces exhibit a kneaded appearance on the matched faces, showing clearly that brecciation has taken place since deposition. The waterworn rounded surface of the original pebble can be readily traced. These dynamic phenomena indicate that the strata along this northern margin have never been under the pressure which has so profoundly acted upon the elongated conglomerate pebbles near Newport, Rhode Island.

The shallowness of the waters—if indeed the deposits were made in a permanent water basin—over this area in Wamsutta time is shown by the current marks on sandstone layers between Whiteville and Easton, and by the coarseness of the sediments.

The structure of the beds is everywhere comparatively simple, their dip being southerly beneath the carbonaceous strata which begin the Rhode Island Coal Measures. Their continuity is frequently interrupted by faults in the manner explained in the discussion of the boundary line from Burnt Swamp Corner eastward.

Gray sandstones of the northern border.—In the small hill near the border northwest of the Shepardville reservoir, in Wrentham, there are exposures of a brownish, sometimes greenish, fine-grained, rather massive rock, which under the microscope is seen to be composed of grains of clastic quartz and feldspar. This rock is at present considered as a member of the Wamsutta series, and, on account of its more extensive development a few miles southward, in North Attleboro, may be called the Attleboro sandstone. The outcrops

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[1] Subaerial decay of rocks, by I. C. Russell: Bull. U. S. Geol. Survey No. 52, 1889, p. 56.

along the northern border are of much importance in that they help to define the stratigraphic position of the rock. It is here interbedded with the red conglomerates and shales.

Traces of this rock are seen at points eastward in the area under discussion. Bowlders of a similar rock bestrew the hillside where the North River passes from the Carboniferous area into the region occupied by the granitites. Here the sandstone is well bedded and alternates with bands of pebbles and slate. This variety of sandstone along the northern border is apparently much thinner than in North Attleboro. The probably volcanic origin of this rock, in the form of ash, is referred to in the account of the occurrences about North Attleboro.

THE NORTH ATTLEBORO AREA.

The most characteristic exposure of the Wamsutta group occurs as a horseshoe-shaped area, open on the north, in the towns of Wrentham and

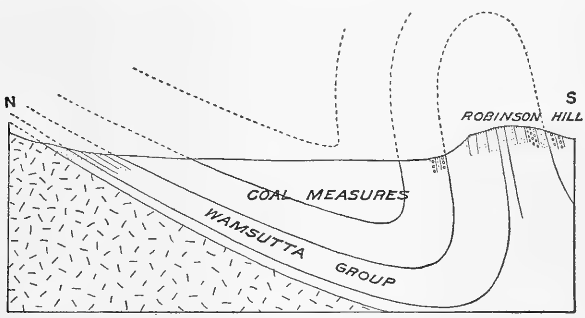

FIG. 12.—Geological section northward from Robinson Hill.

North Attleboro, Massachusetts, and Cumberland, Rhode Island. The formation is a series of conglomerates, sandstones, shales, and calcareous beds with associated felsites, felsite breccias, felsite agglomerates, and diabases. A characteristic of the area is the very great thickness of conglomerates.

Beginning on the northeast, the formation makes its appearance about a mile northeast of the village of North Attleboro, in Robinson Hill (see fig. 12), an eminence which overlooks the valley excavated in the softer strata of the overlying Coal Measures extending westward from Mansfield. The section

from this point to the northern border of the main basin seems to have the form of an overturned syncline, as shown in fig. 12.

From Robinson Hill the red conglomerates, sandstones, and shales can be traced southward, with strikes conforming in direction to the general distribution of the formation, to Reservoir Pond, thence to Rattlesnake Hill and skirting the northern banks of Fourmile Brook. The formation thence trends in a southwesterly direction to South Attleboro. Good exposures may be seen in Red Rock Hill. Immediately west of Washington street and south of Allen road, the sandstones and conglomerates may be seen turning north-northwestward, whence they continue in that general direction as a broad area of red rocks with occasional exposures as far north as the vicinity of Burnt Swamp Corner. A well-marked occurrence of these rocks is found between Abbots Run and Millers River.

The stratigraphy of the area immediately west of the Blake Hill fault block in Plainville, and thence northward to the Sheldonville narrows, is imperfectly understood. About a mile north of the southwest corner of the block, the Wamsutta beds occur in a well. Between this locality and the Blake Hill schoolhouse, 1 mile southeast of Burnt Swamp Corner, gray Carboniferous beds appear in an unknown relation to the red beds above referred to. From the schoolhouse a strip of red conglomerates extends southwestward toward the main belt of these rocks, which here skirt the western border. The varying strikes and the repetition of isolated red and gray outcrops northward in the direction of Red Brush Hill render the structure of this region difficult of interpretation, since the gray beds may belong below or above the red beds, and criteria for the determination of their position are there absent. The boundary line drawn upon the accompanying map (Pl. XVII) between the red and gray series in this region is therefore wholly conjectural. It is probable that the rocks are thrown into closed folds.

Conglomerates.—The conglomerates are composed mainly of waterworn pebbles of greenish quartzite. One pebble in the outcrops in the valley of Abbots Run contained several Obolus shells, which, according to Walcott, are upper Cambrian. Granitic pebbles are common, and locally there is a large proportion of felsite. Stretching and fracturing of pebbles under the pressure of strong folding is evident from point to point in the more disturbed areas. It is probable that conglomerates occur on more than one

PLANT-BEARING OUTCROP OF WAMSUTTA GROUP.

Red Carboniferous shale with conglomerate bands the former carrying carbonaceous casts of calamites Foot rule in view for scale. Locality, 158 Elm street, North Attleboro Massachusetts Looking east of north (1895).

horizon in this field, but on account of the intense folding, along with faulting, it is not satisfactorily determined to what extent the conglomerates are duplicated. Some of the felsitic conglomerates pass into agglomerates, and these into felsite breccias, well shown in the valley east of Oldtown.

Sandstones.—The sandstones of the area under discussion are of variable texture, becoming coarse and feldspathic and thus approaching arkose on one hand and grading into quartzites and shales by the separation of the quartz and decomposed feldspar on the other hand. The reddish quartzitic beds are well exposed on Robinson Hill and in general about the village of North Attleboro. Their detailed representation on the map accompanying this report has not been attempted. In the bend of the sandstone ridges at Red Rock Hill, Mr. H. T. Burr found rain imprints on the sandstone.

Shales.—The shales, or often slaty argillaceous sediments, of the formation are well exposed in the valley between Reservoir Pond and Red Rock Hill. Other exposures occur east of the village of North Attleboro. Reservoir Pond appears to lie partly in a depression excavated along the line of strike of these beds. The shales are frequently interrupted by knobs and sills of felsite (see fig. 14). The beds contain flattened stems of calamites, as at Attleboro Falls, near Reservoir Pond, and east of Red Rock Hill.

THE CENTRAL FALLS AREA.

The Central Falls area is not well exposed. The best outcrops are near the High School in Central Falls. On the east, near the old post-road, conglomerates occur with slaty beds in nearly vertical attitudes. In Pawtucket the beds are mostly red shales or slates at the same high angles. The breadth of the formation decreases rapidly southward along the strike. At the widest part it is as much as 1,000 feet. Its appearance in this part of the field is evidently owing to compressed anticlines and synclines in the highly inclined Carboniferous strata at the head of Narragansett Bay. The structural relations of this area to that in North Attleboro are best explained by an anticline arching over the conglomerates west of South Attleboro. This view also supposes that some of the Coal Measures, i. e., the Pawtucket shales, may be inferior in position to this southern extension of the red beds.

THE PAWTUCKET AREA.

Another small area south of the last, not more than a few yards in width, is exposed in the gorge of the Blackstone River, in the southern part of the city of Pawtucket. At this point the red slates are associated with green slates, recalling a similar association of red and green slaty beds at Pondville, in the Norfolk County Basin. Close folding appears also to be, in this locality, the explanation of the relations which these beds bear to the adjacent carbonaceous beds. This is the southernmost exposure of the red rocks known to me in the basin. Southward and westward in this latitude the red rocks disappear. At only one point on the Little Compton shore do red rocks appear at the surface outside of the areas named, and in this instance they are limited to a thin layer of red hematite in the coal-bearing section. The deposition of the carbonaceous series of the Coal Measures in this southern field preceded the incoming of

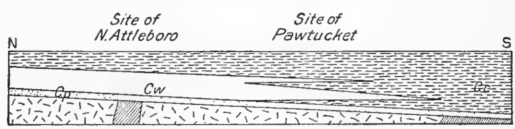

FIG. 13.—Diagram showing disappearance of Wamsutta group (Cw) in the Coal Measures (Cc).

the red material from the north, and continued without interruption south of Pawtucket.

RED BEDS IN ATTLEBORO, REHOBOTH, AND NORTON.

These occurrences are fully considered elsewhere in this report. Reasons will be advanced in the following chapters for regarding at least the first two of these red beds as local deposits formed at different levels in the Coal Measures. The last-named area contains red shales with calamites in the drift a few rods south of the outcrop.

NORFOLK COUNTY BASIN AREA.

No detailed work was done in this basin during the present survey. As a result of a reconnaissance, fossils were found at Canton Junction, confirming the views of Crosby and Barton as to the Carboniferous age of a part of the strata. The rocks closely resemble the red and gray beds along the northern margin of the main basin. Red beds largely predominate in all the exposures. A characteristic basal section has already been described at Pondville. The strata are almost everywhere inclined at very steep

angles. While the section at Pondville indicates simple downfolding of the margin, the form of the basin and the distribution of beds along the border, particularly on the north, are suggestive of downfaulting of the beds in most parts of the basin. The strata are usually not so much metamorphosed as those south of Pawtucket in the main basin. The occurrence of locally metamorphosed conglomerates at Morrills Station (see fig. 6, p. 120), on the Walpole and Wrentham Railroad, illustrates the effect of great pressure in producing the elongation of pebbles and in inducing secondary minerals. In this instance the rock has become very markedly sericitic and disintegrates rapidly.

SOUTH ATTLEBORO LIMESTONE BED.

This name has been chosen for the occurrence of nodular aggregations of calcite and amorphous carbonate of lime which are associated with the red shales of the Wamsutta or red rocks, and which are particularly well displayed in South Attleboro, in the southern base of the hill at the foot of which the town is situated.

A section from the road northward up the hill is as follows:

Section of the Wamsutta formation in South Attleboro, Massachusetts.

	Feet.	In.
Red shales, concealed southward	6	0
Fine conglomerate	2	0
Red shale		6
Limestone bed	6	0
Shales, red	10	0
Conglomerate	5	0
Shales, red, partly covered	119	0
Sandstone, red	24	8
Shales, red, partly concealed	99	2
(Felsite, reddish and irregular in thickness, exhibiting flow structure, 25 ft.)		
Shales, red	28	4
Red conglomerate, coarse pebbles	60	0
Shales, red	60	0
(Diabase, amygdalar cavities on northern aspect, 15 ft.)		
Red shales, concealed northward, measured	175	0

The limestone occupies irregular kidney-shaped cavities in the red shale, or is for a few inches of its thickness in the form of rude layers. Another mode of occurrence is as isolated nodular masses half an inch in diameter. These nodules are frequently elongated in the direction of the

strike. Some of the larger masses, where weathered, show minute rounded apertures, marking closely set pits.

Under the microscope, in thin section, a specimen of the amorphous limestone from this locality appeared as an aggregate of minute grains, occasionally exhibiting large individual grains with distinct cleavage.

Stratigraphically, the limestone is at this point relatively low down in the red series of rocks. The material can be traced westward and northward, by means of bowlders, in the same relative position on the east side of the valley of Abbots Run.

Eastward and northward, limestone is again found on the place of Mr. Todd, near the old Powder House, in North Attleboro; but here the limestone is a mottled marble, which has been used for making quicklime. The limestone bed here occurs in a thick section of sandstones and shales of red color, in no way identifiable with the section in South Attleboro. This occurrence is on a more northern line of outcrop than the former, and if stratigraphically connected with it, is to be explained by a fold such as is suggested by the general structure of this area.

The irregularity of occurrence of the limestone in the different sections where it is exposed, together with its evident secondary origin, has led to no dependence being placed upon it in the course of the survey as a plane of reference in the correlation of strata.

Similar shaly limestone reappears in the Norfolk County Basin, near Canton Junction, Massachusetts, in a section described by me.[1] A closely similar rock occurs in the Cambrian section in North Attleboro, where the limestone has evidently been formed from the remains of pteropods.

These limestones were described by Prof. Edward Hitchcock, and a specimen from the southwest part of Attleboro gave him the following analysis:[2]

Analysis of limestone from Attleboro, Massachusetts.

	Per cent.
$CaCO_3$	94.60
SiO_2 and Al_2O_3	5.40
Total	100.00
Quicklime	52.98
Specific gravity, 2.71.	

[1] Am. Jour. Sci., 3d series, Vol. XLVIII, 1894, p. 147.
[2] Final Report on the Geology of Massachusetts, 1841, p. 80.

The late Prof. T. Sterry Hunt suggested[1] that these limestones intercalated with red slates might correspond with those bands of limestone which are met with in similar red slates and sandstones at the base of the Carboniferous formation in Canada on the Bay of Chaleur and in New Brunswick. It is clear that the deposits lie near the base of the Carboniferous in Massachusetts, but the evidence is as yet lacking that this section corresponds, in the sense of an exact correlation, with the base of the Carboniferous in the Canadian provinces.

Economically, these limestone beds, so far as they have been seen in natural exposures, do not, in the presence of the larger and purer deposit in the neighboring crystalline region of Rhode Island, assume a commercial importance. As a local source of supply for individual uses, they will probably from time to time afford some employment.

ATTLEBORO SANDSTONE.

This is a fine-grained massive sandstone, varying from green to brown in color, the latter hue being due evidently to oxidation.

The massive structure of this rock and the angularity of its particles of quartz and feldspar in many cases, as seen under the microscope, make it likely that it is to be regarded as a volcanic ash deposit, discharged from the vents which gave rise to the felsite flows of this northwestern corner of the basin.

The most instructive exposures of this rock are in the town of North Attleboro. One may be seen just west of the water tower in the northeastern part of the town. A more extensive outcrop is exposed south of Goat Rock and north of the Hoppin Hill granitic area.

Other occurrences of this rock are to be seen embedded with the red series near Robinson Hill, north and east of the first-mentioned locality, and again in the same stratigraphic relation in the vicinity of Deantown, in Attleboro Township. The exposures along the northern margin of the basin, in the Franklin quadrangle, show the position of the deposit to be near the base of the Carboniferous formation. The quartz grains are there much coarser than in North Attleboro.

The stratigraphic relations of the sandstone, where seen, indicate that

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[1] Am. Jour. Sci., 3d series, Vol. XVIII, 1854, p. 199.

it is a member of the Wamsutta series. Fossils have not been found from which to determine the age of the beds independently.

The texture and color of the rock, as well as its position and quantity, would make it fit for building stone but for the fact that it is quite devoid of those sets of joints or bedding planes on which the extraction of suitable blocks depends.

IGNEOUS ASSOCIATES OF THE WAMSUTTA GROUP.

One of the striking features of the Narragansett Basin is the localization of eruptive rocks in the area of the red strata of the Wamsutta group. Dikes occur, however, elsewhere in this region, in Lincoln, near Providence, and at the mouth of Narragansett Bay, marginal to the field.

Diabase.—An interrupted faulted series of narrow, partly altered diabase dikes can be traced from North Attleboro southward around the horseshoe fold of the Wamsutta group to Lanesville and thence northward toward Arnolds Mills. The diabase is usually erupted through red conglomerate, sometimes in the form of twin dikes with a large sliver or wedge of the country rock between. The upper surface of the diabase for a thickness of from 1 to 3 or even more feet is commonly vesicular; sometimes the lower surface is amygdalar; but there is no evidence to show that the diabase flowed out as a contemporaneous sheet.

These dikes are of variable widths from point to point where they appear, attaining thicknesses of from 20 to 50 feet. They frequently rise up as low black knobs, as between North Attleboro and Attleboro Falls, or appear as low bluffs, as on the east bank of Abbots Run and between Adamsdale and South Attleboro. For the most part they crop out along the outer limits of the circular area occupied by the red rocks.

At a number of points these diabase knobs are so situated as to be available for supplies of road stone, for which purpose they are superior to any other rock in this district. The outcrops at Attleboro Falls are within sight of the railroad, and there is a mass adequate for local uses free above ground and now a hindrance to house building.

The ledge on the Henry Guild place in Adamsdale and its continuation northward affords another source of supply—the nearest locality of trap in workable quantity to the cities of Pawtucket and Providence. It would require a carriage of a mile to place the material on the cars of the New York, New Haven and Hartford Railroad at Adamsdale Station. To run a

OUTCROPS OF THE FAULTED DIABASE DIKES AT NORTH ATTLEBORO, MASSACHUSETTS. GLACIAL DRIFT IN FOREGROUND. LOOKING EAST OF SOUTH.

spur of the railroad into the trap locality would necessitate building a bridge or trestle across Abbots Run. From a point half a mile north of the station, it would require about 4,000 feet of track to reach the ledge.

Quartz-porphyries, felsites, and granophyres.—Intimately associated with the red rocks of the Wamsutta group is a series of acid igneous rocks of felsitic and granophyric structure, the distribution of which is parallel with that of the diabase dikes just described, and, like the former, these rocks occur in knobs, whether true bosses or faulted and disjointed dike-like masses being not easily determined. In general they are limited to the horseshoe fold, and do not accompany the Wamsutta group eastward along the northern

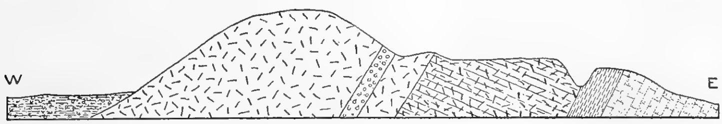


FIG. 14.—Section through felsite knob in Attleboro, Massachusetts. (See table below.)

margin of the basin nor in the Norfolk County Basin beyond the narrows in Wrentham. The felsites are usually of a reddish color.

A cross section (fig. 14) of one of these knobs south of Reservoir Pond illustrates the general character of the association with the Wamsutta group.

The succession, beginning on the east, is:

Section south of Reservoir Pond.

	Feet.
Sandstone (red, pebbly) and shale (red)	40
Diabase	40
Felsite	10
Conglomerate, red	8
Felsite, in large knob	50
(Western contact not seen.)	

The felsites frequently occur higher up stratigraphically than the intruded diabases. The following scheme of arrangement of rocks at three localities will represent this fact:

Stratigraphic relations of felsite and diabase at three localities.

(IV, Z. 24.)	(VII, D. 20.)	(VII, B. 7.)
Red shale.	?	?
?	?	?
Felsite.	Felsite.	Felsite.
Conglomerate.	?	Conglomerate.
Diabase.	Diabase.	Diabase.
Shale.	Shale.	Shale.
Conglomerate.	Conglomerate.	?
?	?	Diabase.
?	Conglomerate.	?
?	?	Shale.
?	?	Conglomerate.

This matching of short sections within 2 or 3 miles of each other, the first two being within half a mile, illustrates something of the constancy of occurrence of these igneous rocks. Regarded as a map, the bottom of the table is east, the top west. The interrogation marks indicate the places of concealed strata. The persistent failure of the western contact of the felsite is a noticeable feature, due to the erosion and concealment of softer material.

The large felsite mass between the village of South Attleboro and Red Rock Hill causes the strata to separate in the manner of a tilted laccolith, but contacts have not been observed which verify the view that it is one. Flow structure, often attended with crumpling of the layers, is manifest in many outcrops of this rock.

Beneath the massive flow of the felsite is a zone of the same rock, forming the matrix of an agglomerate, composed of rounded pebbles of felsite and quartz-porphyry, together with quartzite and occasional pieces of hornblendic granitite. This lower bed is several feet thick. In South Attleboro there is exposed a bed having a thickness of more than 10 feet. The waterworn pebbles are evidently fragments caught up in a movement or flow of the felsite over earlier conglomerates. The groundmass of this agglomerate is porphyritic, with a plagioclase feldspar in every respect like that of the overlying mass.

The eruptions of felsite in this field appear to have taken place sometime after the deposition of the first sediments of the Carboniferous section and before the laying down of the Coal Measures along the northern border. These members of the quartz-porpyhry family of igneous rocks are but outliers of more extensive eruptions of a closely related magma which is extensively intruded into the rocks of the Boston Basin or is found there as ancient flows. In that area the age of the eruptions is not precisely known. If the evidence from the area of the Wamsutta group in North Attleboro and the case in Plympton can be relied upon as evidence, it would point to the Carboniferous age of these eruptives in the vicinity of Boston, and probably to an epoch later than the lower Carboniferous proper.

DIAMOND HILL QUARTZ MASS.

Lying on the western border of the Wamsutta group, but apparently developed in these Carboniferous sediments and in the felsites, is the large mass of vein quartz known as Diamond Hill. The quartz occurs prevailingly in the vein form, with layer upon layer of divergent pyramidal-faced crystals. Locally the quartz is chalcedonic and white, earthy, opaline, the whole being evidently the product of hot springs following the decadence of igneous action in this area.

Quartz veins having the same structure and habit penetrate the red sandstones of the Wamsutta group along the northern boundary in Wrentham. This habit of crystallization has not been detected elsewhere in the basin, although extensive quartz masses occur at other points, as at Mount Hope, and in less abundance southward in the bay region. It is highly probable that the deposition of this quartz took place during Wamsutta time.

WAMSUTTA VOLCANOES.

The peculiar features of the Wamsutta series—the rapid thickening of the sandstones and conglomerates toward the northwest corner of the present area, the felsites with definite flow structure, the gray ash beds or Attleboro sandstone, the agglomerates of felsitic material, and the associated conglomerates composed in large part of felsite pebbles—all point to a volcano or volcanoes existing in this field in Carboniferous time. The known petrographic connection between the flow structure of felsites in extrusive masses and the coarser structure of typical granite-porphyries in stocks and dikes brings

the phenomena of the Wamsutta series in North Attleboro and the underlying terrane of schists with intrusive granite-porphyries in Cumberland into an interpretable relation. On the one hand, we have the effusive products of volcanic action; on the other hand, the underground conduits and rents filled with their equivalent portions of the magma.

The same story is fairly derived from the Blue Hill region on the north side of the Norfolk County Basin. The beginning of sedimentation in this part of the Carboniferous land area appears clearly to have been accompanied by extensive acid eruptions. It is probable, as above noted, that the large felsite area about Boston was formed also in Wamsutta time. How much later the action continued can not be readily determined. The intrusion of pegmatitic granites in the southern arm of the Narragansett Basin, in the vicinity of Watsons Pier, together with the marked local metamorphism of all the Carboniferous strata in that portion of the area, shows that volcanic action held on there later than in the northern fields, if it did

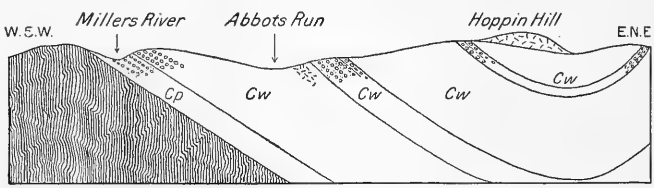


FIG. 15.—Geological section in the Millers River region.

not altogether take place later than the deposition of the Carboniferous strata in this part of the continent.

FOLDING OF THE WAMSUTTA GROUP.

The folds of the strata of the red Wamsutta series in North Attleboro are the most complicated that have been found in the Narragansett Basin. The large horseshoe-shaped area of red rocks above described wraps around the older granitite and Cambrian rock of Hoppin Hill, so that the general structure is anticlinal; but the dips of the beds are now in many places inward toward the center, giving rise to an apparent synclinal structure. On the east, from the village of North Attleboro southward to South Attleboro, the dips of the red beds are mainly inward toward the Hoppin Hill area, until at the latter place they become very

low, as in the nose of a broad shallow syncline (see fig. 15). On the western arm of the area the dips vary from east to west. Such marked inversion of strata warrants the explanation that the beds have been compressed into the fan structure by the marginal collapse of a more or less quaquaversal anticline which formed over the Hoppin Hill inlier. It is owing to this extreme folding, together with the imperfection of the exposures by reason of glacial drift, that the region is so difficult of interpretation. Northward, near Arnolds Mill, the apparent structure is indicated in the section, fig. 16.

In the southern areas of red rocks in Pawtucket there is the most satisfactory reason for believing that the broad exposures of alternating red and gray rocks are due to close folding. This district, indeed, furnishes a clue to the structure of the nearly vertical beds southward along the

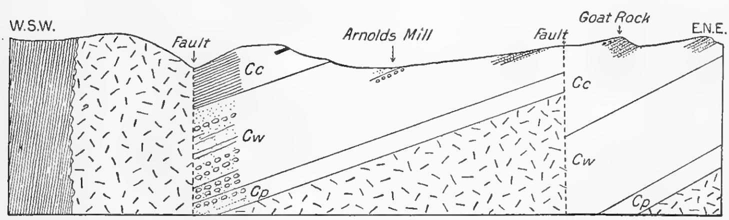


FIG. 16.—Geological section in the Arnolds Mills region.

western margin of the Narragansett Basin, in the Cranston beds, and in the equivalent Kingstown series, described by Dr. Foerste in another section of this monograph.

This same field, showing the red and gray Carboniferous strata folded into isoclinal relations, affords strong evidence for believing that the Wamsutta series, in the main basin at least, was not folded until the deposition of the Coal Measures, and that the entire thick section of sediments in the basin underwent plication after the period of deposition. All the facts from various points in the field support the view that there was but one period of elevation, and not two, as was formerly thought by Edward Hitchcock. There are a few disturbances along the northern margin in the Wamsutta area, which have been thought to indicate an upturning of the red series before the deposition of the Coal Measures in that section, but to my mind the evidence is not clearly demonstrative of this view.

Several small faults exist in the North Attleboro area between Robinson Hill and South Attleboro. These dislocations are indicated by the offset of diabase dikes along their line of strike, by the occurrence of beds in blocks, and also by the exposures in which the dislocation may be traced. In front of the house of Mr. H. Rhodes, about 1½ miles northeast of South Attleboro, reddish sandstones are brought against the red slates, but this relation is probably due to local unconformity rather than to a fault.

FLORA OF THE WAMSUTTA GROUP.

So far as the observations of the present survey go, the sole fossils found in the red shales and sandstones of this series by Dr. Foerste and myself are a species of calamites and a cordaites. As a whole, the strata are prevailingly barren, a characteristic of red rocks everywhere. Enough of the flora is known, however, taken together with the stratigraphy, to warrant placing the beds in the Carboniferous section of the Narragansett Basin. This fully confirms the views of Crosby and Barton expressed in 1880.

The geographical conditions under which the beds were laid down seem to have been incompatible with the accumulation of plant remains in the area of sedimentation, rather than that there is any difficulty in preserving fossils of this kind in red beds. In places abundant traces of calamites occur in the form of good impressions without a trace of Carbonaceous matter. In other localities the impressions of single stems are black with carbon, and had enough of these fragments been accumulated in one plane a black shale layer, if not a deposit of coal, must undoubtedly have resulted.

There are reasons for believing that southward beyond the limits of the red beds plant remains were accumulating at this early stage in the Carboniferous of the Rhode Island area. The general absence of fossils in this series appears to have been due to a control exercised by the peculiar processes concerned in the deposition of the series itself. The presence of quartz-porphyry pebbles along with masses of this rock and the related felsite, which appear to have come into their present relation to the strata before the deposition of the Coal Measures in this part of the field, suggests that volcanic action may have affected the formation of sediments in a way to be locally unfavorable to the growth and preservation of plants.

COAL MEASURES.

The Rhode Island Coal Measures, if we use this term to comprise all the horizons on which coal has been reported, include at one point or another in the basin all the strata from near the base to the great conglomerate bed which occurs at the bottom of the Dighton group. The estimated thickness of this section is about 10,000 feet.

There is reason to believe that the lowest members of this great thickness of sediments are, from Pawtucket southward, the time equivalents of the Wamsutta group. The relations of the Wamsutta series of red and green slates to the coal shales may be seen to advantage in the gorge of the Blackstone River at Pawtucket.

The very considerable thickness of the beds between the basal arkoses and the conglomerates and the overlying Dighton group of conglomerates has rendered it possible to make certain divisions in this great middle section which have a geographical value and indicate at the same time lithological peculiarities. On these grounds four groups have been denominated, it not being satisfactorily determined whether the strata of the lower two beds are exactly equivalent or not.

The supposed relations of these to the beds recognized by Dr. Foerste farther south are indicated in the table on page 134.

In the following notes concerning the northern area local names will be employed, with such chronological limitations as present knowledge of the field will permit

CRANSTON BEDS: KINGSTOWN SERIES OF DR. FOERSTE.

PROVIDENCE AREA.

It is the general opinion of those who have examined the rocks west of Narragansett Bay in the vicinity of Providence that the strata of the Coal Measures are here nearer the base of the series than those which lie immediately on the east of Providence. This supposition is borne out by the structure of the sections which can be drawn for this region.

The strata of this area from Pawtucket southward, to the limits of the Providence sheet, exhibit generally very steep dips prevailingly eastward. The strikes are generally east of north, being more persistent in the sand-

stone beds than in the shales, the latter being very much crumpled and often striking east and west.

The metamorphism of this belt allies it petrographically with the area southward in the lower part of Narragansett Bay. The sandy and pebbly beds, however, exhibit less dynamic metamorphism, but the shales above exhibit in a marked degree the development of new minerals which has resulted from this change.

There are three well-marked north-south troughs about Providence in which the softer argillaceous beds occur, separated by more resistant arenaceous strata standing out as ridges. Beginning on the west, and next

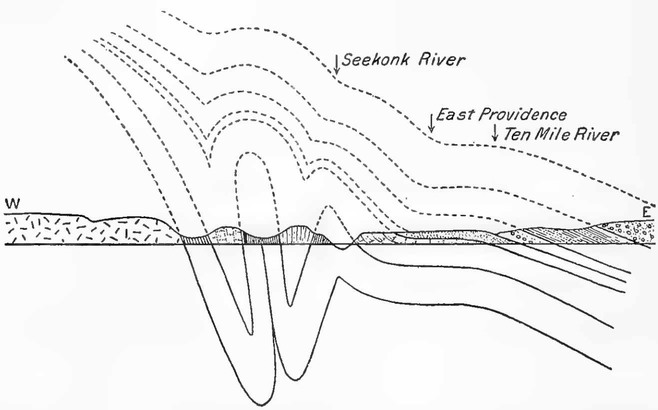


Fig. 17.—Hypothetical geological section east and west through Providence, Rhode Island, showing supposed relations of Cranston and Tenmile River beds.

the escarpment which marks the crystalline and igneous border, there is the depression between it and Sockanosset, Rocky, Sky High, Bradley, and Windmill hills. The structure and character of the strata occupying this depression can be inferred only from isolated observations, mainly in the "dugway" in the southwestern part of Cranston, where the basal beds of the Carboniferous cling to the escarpment in a recess. The next trough on the east, which opens out into the bay south of Providence, is very thoroughly filled in with glacial sand plains. The occurrence of conglomerates toward the south and the evidence from borings in the vicinity of Providence are the sole indications of the stratigraphy.

The coal from Cranston afforded F. A. Gooch the following analysis:[1]

Analysis of coal from Cranston, Rhode Island.

	Per cent.
Water	0.24
Volatile matter	4.49
Fixed carbon	82.20
Ash	13.07
Total	100.00
Sulphur	0.34
Specific gravity, 2.209 at 150°.	

These troughs appear to be mainly underlain by coal-bearing shales. The Sockanosset mine in Cranston comes in this section. In the valley north of Providence the shales crop out in a cut in the Old Colony Railroad.

A well sunk in Butler street, corner of Bassett street, in 1895, penetrated the Coal Measures. Samples of the materials brought up from certain depths were furnished the Survey, through Mr. N. H. Darton, by Mr. C. A. Ray, of East Providence, Rhode Island. The following table sets forth the data obtained from this well.

Record of well sunk in Providence, Rhode Island, in 1895.

	Depth in feet.
Schist, soft, black, graphitic; with water turning to graphitic mud, somewhat too gritty for lubricating purposes	126
Schist, micaceous, carbonaceous, carrying large cubical iron pyrites	176
Schist, carbonaceous	309
Schist, graphitic	341
Grit, or metamorphic sandstone	352.5
Schist, graphitic, with fragments of vein quartz	419
Coal, anthracitic; very light, with small cubic fracture and some irregular patches of dull black carbon	460
Coal, cut by veins of quartz, subfibrous near walls	475
Coal, with small cubical fracture and more of the dull lusterless carbon, about	477
Schist, heavy, black, graphitic, pyritiferous, about	477
Schist, fine micaceous, pyritiferous in layers	492

[1] Report of work done in the Washington laboratory during the fiscal year 1883-84: Bull. U. S. Geol. Survey No. 9, 1884, p. 18.

Pawtucket shales.—Still farther northward in Pawtucket the shales are well exposed in the banks of the Blackstone River on Division street, and at Valley Falls they are exploited in a graphite mine.

The best natural exposure is along the eastward bend of the Blackstone River between Central Falls and Valley Falls, where, on the south bank of the river, a section of bluish and black carbonaceous shales, with fossils, is thrown into a broken fold with minor contortions (see fig. 18). The strike here is approximately east and west, and the dips are steep, mainly 80° N. The beds evidently overlie the grits and red series half a mile south. The slate layers contain distorted and disjointed fragments of plants. Further evidence of the movement which the rock has under-

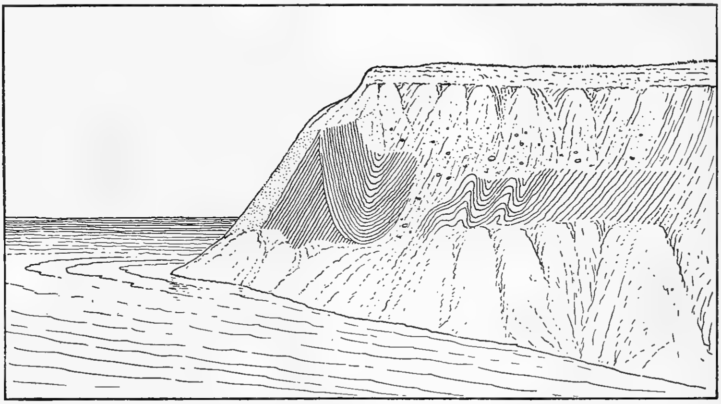


Fig. 18.—Folded and faulted Carboniferous shales on the Blackstone River at Pawtucket, Rhode Island. (Looking east.)

gone is shown in minute joints, in antiparallel sets, accompanying small puckerings of the slate. Along each joint plane there has been a minute fault movement of the normal kind.

The thickness of the beds included under the term Pawtucket shales, if we place here all the soft beds in the troughs so far described, can not be safely stated. If the structure about Providence is due to the duplication of beds by overturned folds, as indicated in the theoretical section (fig. 17, p. 160), and since there are at least 3,500 feet of beds between the sandstones of the western or Sockanosset ridge and the base or western boundary, the apparently great thickness of beds in the other valleys may be readily

ROCKY HILL, PROVIDENCE, RHODE ISLAND, A GLACIATED RIDGE OF CARBONIFEROUS STRATA. LOOKING WEST.

explained. How much of this section is to be allotted to the shales alone is not known.

Sockanosset sandstones.—The ridges in this area, including the ridge in the East Side area, are evidently due to the presence of sandstones and conglomeratic beds. They are well exposed on Sockanosset ridge east and west of the reservoir. They are members of the Kingstown series of Dr. Foerste. The shales are carried well up on the eastern flanks of these hills. Pl. V represents a side view of Rocky Hill, showing the glaciated northern slope.

EAST SIDE AREA IN PROVIDENCE.

Knowledge of the stratigraphy of this area is limited to a few outcrops and to occasional borings, the latter of which have been recorded by the Providence Franklin Society.[1]

The rocks consist of sandstones, shales, and pebbly beds, exhibiting the aspects of metamorphism commonly found farther south at Sockanosset and in the lower bay region. The schists are frequently highly carbonaceous.

The rock reported to have been taken from the ledge on which Roger Williams landed is a black metamorphic shale, or ilmenite-schist, soft and readily falling to pieces under abrasion. This rock evidently gives rise to the depression in which the Providence and Seekonk rivers run.

The attitude of the strata in this area is exhibited in the outcrop opposite No. 75 East George street, near Gano street. There are here about 38 feet of slates with arenaceous and pebbly beds, all showing signs of crumpling under great pressure and standing at angles of dip as high as 80°. The beds strike N. 25° E. magnetic (N. 14° E.), dipping in one place E., in another W. The fine conglomerates contain quartz and quartzite pebbles. There is a pronounced cleavage, for the most part striking N. 65° W. magnetic (N. 76° W.), and dipping about 60° N. This secondary structure seems generally to have been taken by the inexpert for stratification. Similar exposures exist on the hill to the west. Rock is also reported to have been struck in borings at a few feet from the surface and in making excavations for the reservoir. Coal is said to have been met with on Benefit street south of Church and Stair streets.

On the land of the Swan Point Cemetery, between Swan Point road and Blackstone boulevard, is a small outcrop of massive grayish sandstone,

[1] Geology of Rhode Island, 1887, Addenda, pp. 129-130, 1888.

such as is characteristic of the Coal Measures on the east side of Providence River. The rock exhibits a fissile structure, striking N. 25° E. magnetic (N. 14° E.) and dipping 60° E. These figures give also, I believe, the approximate attitude of the stratum

TENMILE RIVER BEDS.

The Coal Measures east of the Providence and Seekonk rivers as far as the eastern bank of the Tenmile River afford characteristic exposures of slightly altered sandstone, pebbly beds, and shales. Coal has been found in the bed of Tenmile River. These strata may for reference be denoted as the Tenmile River beds. The essential features of this horizon are set forth in the following description of localities. If the beds on the west side of the Seekonk and Providence rivers are, as the local structures indicate, in an anticlinal relation with those on the east side of those streams, the metamorphosed shales and sandstone of the Cranston series are the equivalent of the Tenmile River beds. For the present it seems best to consider the beds as two geographical groups. The presence of the Odontopteris flora and the insect fauna in the Tenmile River beds allies them, it should be noted, with the metamorphosed strata at Pawtucket and Sockanosset, and favors the idea that the two series are essentially at the same horizon, though it is probable that the Tenmile beds do not, as does the Cranston series, run downward to the base of the Coal Measures. (See fig. 17, p. 160.)

LEBANON MILLS EXPOSURE.

A low outcrop in which there is a small quarry occurs on the west bank of the Tenmile River at Lebanon Mills. The beds are conglomerates, sandstones, and slaty shales, striking N. 48° E. and dipping 70° S. One of the slaty layers contains worm burrows and plant stems (Sigillaria, Calamites), and the beds have here and there a reddish hue. The beds clearly underlie those on the east bank of the river.

EAST PROVIDENCE AREA.

Very good exposures occur in the southern part of the town of East Providence, Rhode Island, in quarries near Leonards Corners, and particularly along the shore of Narragansett Bay from Watchemocket Cove southward to near Sabins Point. The strata in this area are in marked contrast to the exposures on the west side of the Seekonk and Providence rivers,

as regards both attitude and alteration. They not only lie in less disturbed positions, but they preserve to a much greater degree their original clastic texture, and fossils are of frequent occurrence in them. An account of the more typical exposures as they now exist follows:

Leonards Corner quarries.—In the southeastern triangle formed by the roads, at an elevation of about 100 feet above the sea, is an exposure of pebbly sandstone on the site of a rock crusher. The strike here is about east-west and the dip very gently to the south. An unidentifiable fossil tree, over 9 feet in length and from 6 to 8 inches in diameter, lies prostrate in the bedding, with its major axis east-west.

A half mile east of the outcrop just described, about 25 feet of the coarse pebbly sandstone of the Carboniferous are exposed in Mr. John McCormick's quarry. The beds are massive, essentially horizontal, with traces of coaly shales and coal, the last mostly marking the sites of single plants. The following plants were found:

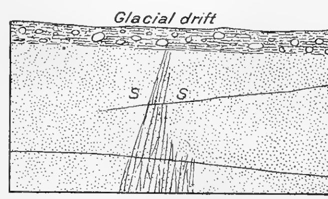


Fig. 19.—Sketch of zone of excessively jointed sandstones (SS), face of McCormick's quarry.

Calamites suckovii, in large, well-preserved forms, showing inner markings. One large specimen, somewhat flattened, was preserved in a coat of wad, a replacement of the cortical layer probably after carbonate of lime. This stem lay nearly east-west, as did others in the same quarry, but the plants are disseminated and occur at no particular level, indicating the occasional drifting in of floating trees and the rapid accumulation of the sands and pebbles.

Sigillaria? Long, slightly tapering, flattened stems, with longitudinal striations, but without cross markings, occur in this section, usually preserved as internal casts in sandstone. They may be ill-preserved calamites.

In the rubbish in the bottom of the quarry, but evidently transported, were fragments of shale with raindrop impressions.

The sandstone beds are traversed by a fault striking N. 44° W., with a hade of 10° S., and the well-marked slickensides have a uniform pitch on the exposed wall of 55° NW. This dislocation can not be of any considerable extent, for the same sandstones lie on both sides of the plane of division. Another set of divisional planes, in the form of very close-set joints, striking N. 46° E., divides the sandstone along a belt of variable width into

blocks too small for building purposes. (See fig. 19.) This zone of jointed rock widens from not more than 2 feet at the present surface to 10 or 12 feet at a depth of 20 feet.

Section from Watchemocket Cove to Riverside.—The rocks which appear in the quarries above described come to the seashore in bold cliffs between Watchemocket Cove and Riverside, and in a few places the natural section has been made clearer by railway cuts. About 100 feet in thickness of Carboniferous sandstones, conglomerates, and shales are exposed along this section, in the form of a broad, flat syncline from Watchemocket Cove to near Pomham Rock, where the strata become vertical and are much disturbed, at one point the sandstone beds having been reduced to breccia. The strata just south of Silver Spring form terraces overlooking the bay. Northeastward from Pomham Rock and Riverside the same strata are seen inland in the three ridges indicated on the topographic map. In the eastern one of these long, low ridges, the sandy conglomerates dip northwestward at a very low angle, but the strata in the westernmost of the ridges dip steeply east, being along the line of the Pomham anticline. Northeastward, at a point about a mile due east from Vue de l' Eau, the strata turn more to the eastward, as if in the canoe end of a syncline. (See fig. 20.)

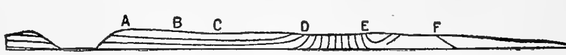


FIG. 20.—Geological section from Watchemocket Cove to Riverside, Rhode Island, showing the attitude of the Carboniferous strata. A, Kettle Point; B, Squantum; C, Silver Spring; D, Pomham Rock; E, Riverside; F, Outcrop near Sherman Station.

South of Riverside the rocks are not well exposed. The details of stratigraphy along this shore are sufficiently illustrated in the following notes:

Halsey Farm section at Silver Spring.—A few rods south of Silver Spring Station the following section was measured in the bluff at Halsey Farm:

Section in bluff near Silver Spring Station, Rhode Island.

	Feet.
Sandstone and conglomerate (at top)	40
Conglomerate with pebbles of quartzite and granite	6
Sandstone (to bottom)	4

These strata are approximately horizontal, but farther east they dip eastwardly, and westward across the railroad track they dip as high as

EASTWARD-DIPPING CARBONIFEROUS SANDSTONES AND GRITS AT SILVER SPRING, RHODE ISLAND. LOOKING NORTH.

45° E. In the railway cut the same series of strata show a north-south vertical fault plane, the slickensides of which are horizontal. There is

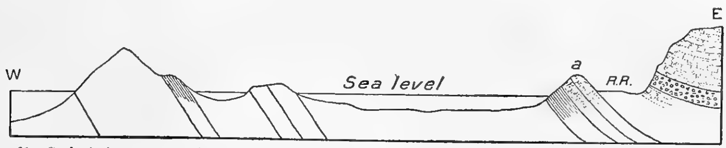


FIG. 21.—Geological section through rocky islets at Halsey Farm, Silver Spring. a, the rocky head shown in Pl. VI; R. R., the railroad.

present a coarse slaty cleavage, but it is not a constant feature. The joint planes display great feathery surfaces of fracture, the divergent lines of which indicate the direction of splitting; this sometimes is upward or downward, but very frequently in a horizontal direction, the plane being vertical. With certain precautions, the dip of massive beds can be obtained by observing the inclination of the axes of these feather fractures. The joint planes frequently die out with a convex front, the periphery being cast into concentric flexures of conchoidal fracture, often measuring an inch from trough to crest. These planes of fracture exhibit splitting figures having a length of at least 6 feet from the rather indistinct point of origin to the sharply incised marginal rugosities.[1]

A few rods farther south, but north of Pomham Rock, is a small rocky headland, composed of two distinct ridges, in which the following section was shown, dipping 45° E., the same rocks reappearing in the islets northward by the Silver Spring shore.

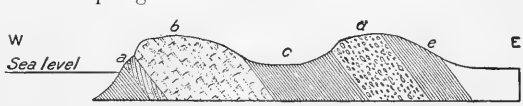


FIG. 22.—Geological section of rocky headland below Halsey Farm Bluff, near Silver Spring, Rhode Island. (For explanation of letters, see accompanying section.)

Section in rocky headland near Silver Spring Station, Rhode Island.

	Feet.
e. Slate (at top)	15
d. Grits	15
c. Slates, partly covered	25
b. Grits and sandstones, with pebbles, isolated, and in bands and pockets	15
a. Slates with sandy layers, showing local unconformity to b, due to contemporaneous erosion; plant stems occur, and the upper portion of the bed is carbonaceous; cross bedding very marked; exposed above high-tide mark	6

[1] For a detailed description of this type of fractures, see paper "On the fracture system of joints, etc.," by the author: Proc. Boston Soc. Nat. Hist., Vol. XXVII, 1896, pp. 163-183.

Fossils.—North of the station black shales contain impressions of *Sphenophyllum schlotheimii*, both alone and with *Asterophyllites equisetiformis*. Pecopteris, smaller than *P. unita*, also occurs here. In the mudstones on the bluff calamites are abundant.

In the rocky points and islets along the shore near Silver Spring the dips steepen to 45°, rising to an anticline arching over the upper narrow end of Narragansett Bay—the southward continuation of the fold which is more clearly indicated by the outcrops on the sides of the Seekonk River. The southward extension of this anticline is not readily traceable. The sandstones and conglomerates reappear in the ledge at the present mouth of the Pawtuxet River, and again at Rocky Point, on the west side of the bay.

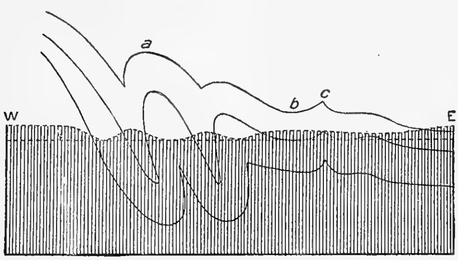


FIG. 23.—Theoretical section of folded structure on western margin of the Narragansett Basin. *a*, Providence anticlinal belt; *b*, East Providence flat syncline; *c*, Pomham Rock anticline. (See Pl. LXXXII, figs. f–i, Thirteenth Ann. Rept. U. S. Geol. Survey, Part II.)

It is evident from a diagnosis of the dips in Providence and East Providence that the strata in this section, from the western boundary eastward into the middle of the basin, behave very much in the manner of the layers under horizontal pressure in the clay models experimented upon by Mr. Bailey Willis.[1] The general structure of a cross section from back of Providence southeastward to Riverside is represented in the accompanying diagram, fig. 23. It will be noticed that there is a belt of very highly tilted strata next the resisting pre-Carboniferous terrane, in which the effects of great pressure are manifest also by the degree of metamorphism; thence eastward lies a belt of little-disturbed strata without any marked metamorphism or even slaty cleavage; there come in then subordinate anticlines with a slight amount of rock crushing. These two anticlinal axes correspond to what Mr. Willis terms consequent and subsequent anticlines, respectively.

It is a noticeable feature of many of the folds in this part of the basin that the inclination of the strata increases to a maximum near the axis.

[1] The mechanics of Appalachian structure: Thirteenth Ann. Rept. U. S. Geol. Survey, Part II, 1893, pp. 211–289.

EXPOSURES IN THE TOWN OF SEEKONK.

The lowest strata exposed in this town occur along the east bank of Tenmile River.

Section at Hunts Mills.—In December, 1892, a pit was sunk into the bed of the stream at this point for the installation of a turbine water wheel. A bed of coal in the following stratigraphic position was penetrated, the overlying beds being exposed in the banks of the river:

Section at Hunts Mills, Rhode Island.

	Feet.
Sandstone, of the graywacke type. Near the falls are large impressions of unidentified plant stems	40
Conglomerate, medium-sized pebbles, quartzose	5
Sandstone	10
Coal, anthracitic, showing slickensides, local crushing, and gash veins, with a white asbestiform mineral	3½
Shale, black, varying from a fine-grained compact argillite to an arenaceous rock; thickness unmeasured.	

These strata dip gently to the north of east. The coal, uniformly like that on the east side of the Seekonk River, is much less graphitic and altered than that which comes from the west of that line in the metamorphosed belt. It is granular and is traversed by small quartz and calcite veins. The strike of this bed would carry the coal along the present path of the Tenmile River northward for several miles. No attempt has been made to use this coal or to explore the underlying shales at other points in this vicinity for other like deposits.

North of Hunts Mills, and about a mile south of Lebanon Mills, a heavy-bedded sandstone crops out on the east bank of the river.

In the northern part of the town, strata approximately on the horizon of the Tenmile River beds, and subjacent thereto, have been explored for coal. One-fourth of a mile east of Perrins Station, on the Fox Point Railroad, is an outcrop of conglomerate and sandstone near the horizon of the upper part of the Hunts Mills beds.

Perrins anticline.—Between Perrins and East Junction, in the cut on the railroad to Fox Point, is an anticlinal exposure of the lowest beds seen in

Seekonk. The axis of this fold is probably that also of the great anticline which lies between the Attleboro syncline and the Great Meadow Hill syncline. The axial plane is overturned to the north. On the northern side of the cut, sandstones and conglomerates dip NNW. at an angle of 45°; in the southern half, sandstone beds with fossiliferous shales dip SSE. at angles from 30° to 15°. There are no exposures at the point where the anticlinal strata would be expected to connect the two parts of the section in an arch, and evidence of an overthrust is wanting.

Fossils.—Several species of plants have been found in a good state of preservation in the shales. The fronds of a species of Odontopteris are usually graphitized and shining. One layer in the sandstones is covered with the impressions of large Pecopteris fronds matted together, but showing the spore cases. The following fossils were found at this locality: *Cordaites* sp., *Pecopteris unita*, *Odontopteris* sp., *Calamites* sp.

Bored well near Lebanon Mills.—About half a mile west of the fossiliferous beds above described, on the land of Mr. L. W. Bourn, a boring was made about fifteen years ago. The hole reached a depth of 705 feet 4½ inches, the surface of the ground being about 90 feet above sea level. The uppermost stratum underlies the shale section in the Perrins anticline. The following strata were passed through, according to a copy of the record in the possession of Professor Shaler:

Geological column of diamond-drill hole made for the Seekonk Coal Mining Company on their anthracite coal lands, Bristol County, Massachusetts, under the direction of Thos. S. Ridgway, geologist and mining engineer.

	Feet.	Inches.
Sand, gravel, and bowlders	54	0
Argillaceous slate, containing impressions of coal plants	4	0
Siliceous grit, alternating with argillaceous slates	13	6.5
Gray sandstone, micaceous, fine grained	9	9
Gray sandstone, coarse and fine, alternating with red, bluish, purple, and olive-colored variegated shales	34	4
Sandstone, compact, bluish, containing seams of slate	17	4
Gray grit rock and sandstone, micaceous slates alternating	18	10
Bluish sandstone, micaceous, alternating with rock binds; lower part shaly, containing impressions of coal plants	17	0
Gray micaceous sandstones, with layers of grit rock and slate	12	9
Argillaceous rock and thin beds of sandstones with seams of slate	9	10

Geological column of diamond-drill hole made for the Seekonk Coal Mining Company on their anthracite coal lands, etc.—Continued.

	Feet.	Inches.
Argillaceous rock, variegated, lower part thin layers of slate	12	0
Bluish sandstone	8	0
Sandstone, mustard-seed grit	24	0
Compact gray sandstone	7	4
Slate and sandstone alternating	8	6
Sandstone and grit alternating, mustard-seed grit	12	9
Sandstone, coarse and fine, micaceous, thin seams of slate	8	4
Argillaceous slates containing thin seams of *coal* and impressions of plants	9	4.5
Coarse and fine micaceous sandstones (depth, 288.5 feet)	6	9.5
Conglomerate	32	4
Red conglomerate rock; slate containing streaks of *coal;* Gray sandstones and *coal* slates alternating	8	3
Gray sandstones, coarse and fine micaceous, separated by argillaceous binds	22	3
Rock binds and sandstones containing veins of quartz	18	0
Coal slates containing impressions of coal plants; lower parts dark sandstone	7	7
Gray sandstone and argillaceous rock	8	0
Dark-colored sandstone and carbonaceous slate	7	0
Sandstone, micaceous, and *coal* slates containing impressions of coal plants	10	0
Coarse sandstone, micaceous	8	10
Coarse sandstone, lower part containing thin seams of *anthracite;* sandstone, micaceous and conglomeratic	14	5
Conglomerate (depth, 425.15 feet)	7	0
Gray sandstone, micaceous	13	4
Conglomerate	4	9
Gray sandstone and slate	3	11
Gray sandstone, micaceous, containing slate with plant impressions	8	2
Sandstone and slate, alternating, containing thin seams of *coal*	4	7
Fine-grained sandstone containing thin seams of slate and *coal* with impressions	5	3
Coal slates containing coal plants; upper part sandy (depth, 479.15 feet)	7	8
Gray sandstone, fine grained, micaceous	13	6
Dark-gray grit rock	7	9
Slate and sandstone, 2 feet; dark-gray grit, 3 feet 4 inches; sandstone and seam of slate, 3 feet 3 inches	8	7
Gray sandstone, 3 feet 5 inches; binds, 6 feet 7 inches	10	0
Gray sandstone	6	6
Binds, 2 feet 7 inches; slate containing plant impressions; supposed thin seam of *coal*, 2 feet 6 inches (depth, 531 feet 2.5 inches)	5	1

Geological column of diamond-drill hole made for the Seekonk Coal Mining Company on their anthracite coal lands, etc.—Continued.

	Feet.	Inches.
Coal slates with impressions, 2 feet 2 inches; sandstone and slates alternating, 6 feet 6 inches	8	8
Gray sandstone, micaceous, fine grained and variegated	48	10
Slate, 2 feet 7 inches; dark-colored sandstone, 4 feet 6 inches; supposed thin seam of *coal*, 1 foot 8 inches (depth, 597 feet 5.5 inches)	8	9
Dark-colored micaceous sandstone	7	5
Slate containing streaks of *coal*	4	7
Dark-gray micaceous sandstone and slate	11	8
Carbonaceous slate and trace of *coal*, 9 inches; fine-grained sandstone and slate, 2 feet 4 inches (depth, 621 feet 1.5 inches)	3	1
Brownish micaceous sandstone	5	3
Slate and sandstone	6	4
Dark-colored micaceous sandstone and slate containing calc spar in veins	8	11
Slate containing impressions of coal plants	7	9
Gray and brownish sandstones	7	10
Gray sandstone with bands of slate	7	9
Sandstone and slate	5	3
(Unnamed rock)	6	7
Slate and sandstone	8	5
Dark-gray sandstone, top roof, 7 feet 6 inches; carbonaceous slates containing impressions of coal plants, 9 feet 9 inches	17	1
Bed of anthracite *coal* (?). (See statement below.) (Depth, 700 feet 7.5 inches.)	8	11
Slate containing vegetable impressions	4	9

The coal bed reported in the above table at the bottom of the hole is said to have been a fraud. According to Dr. Arthur B. Emmons,[1] "no coal core was ever cut in the hole, and the coal core exhibited as having been so cut was cut at the top of the hole from a piece of coal brought onto the ground for the purpose."

In June, 1895, I visited the locality, and from an examination of some of the cores then obtainable on the place was able to make out the dip of the beds as varying from 10 to 15 degrees, figures which agree with the southward dips of the strata on the same strike line in Perrins railway cut. The red conglomerate which appears at a depth of 320 feet is suggestive of the reappearance of members of the Wamsutta series; but from a comparison of the section of this portion of the Coal Measures it is difficult to conceive

[1] Trans. Am. Inst. Min. Eng., Vol. XIII, 1885, p. 517.

that all the red beds lying on the outskirts of the great Wamsutta mass belong on the same horizon. In a red slate core there could be seen annelid casts, such as characterize the red slates on the south side of the Attleboro syncline (see p. 178). It is to be noted also that about 1 mile northeast of Perrins cut the red series is exposed in the northeast corner of the town of Rehoboth. Red shales here also contain annelid tubes.

The stratigraphic thickness of the boring, on the doubtful assumption of the parallel dip of the beds to the bottom, is about 628 feet. There are upward of 1,800 feet of measures to the highest exposures just above the Seekonk conglomerate, and there are upward of 2,000 feet of concealed measures from this horizon upward to Great Rock, where coarse conglomerates, supposed to be of the Dighton horizon, come in. This calculation gives the group of Coal Measures below the Dighton conglomerate in this section a minimum thickness exceeding 5,000 feet. If 5,000 feet of strata below the Dighton conglomerate are measured, in the typical area on either side of the synclinal axis in Dighton and Swansea, it will appear that the bottom of the series is here by no means reached. I am therefore led to place the beds just described relatively high up in the Coal Measures.

SEEKONK BEDS.

About a mile east of the Tenmile River beds, and about 1,000 feet higher up stratigraphically, is a series of monoclinal ridges of sandstone and conglomerate which afford the best natural exposition of the Carboniferous strata that is found anywhere in the inland portion of the basin. While sandstones form the dominant exposures and leading topographical feature of this series, shales enter about equally into the thickness of the beds.

West and south of the farm of Mr. Davis Carpenter these arenaceous and gritty rocks rise from 20 to 30 feet in height, in an area of about 1 square mile, in five principal ridges, striking a few degrees E. of N. and dipping E. from 20° to 30°. The aggregate thickness, including sandstone and shale below a thick conglomerate bed, is somewhat less than 2,000 feet. There is no evidence to show that the successive ridges are due to the repetition of step faults bringing up a single bed. East of the stream on the Woodard place, in the southeastern part of the area of exposures, a sandstone ridge has been quarried, the strata here affording rough, thick flags. The large strike joints which occur here are very smooth and nearly par-

allel, but the dip joints are much less regular planes. One-fourth of a mile west of this locality there is a long ridge of alternating grits and conglomerates, probably the outcrop of the heavy conglomerate which comes in more distinctly farther north. The beds are penetrated by nests and veins of white quartz. In the shales underlying one of the sandstone ridges impressions of calamites and asterophyllites were found in the course of the present survey by Mr. W. E. Parsons.

Seekonk conglomerate.—North of this area, about a mile along the strike, the geological structure and topographical features are repeated. The Seekonk conglomerate bed here becomes more pronounced and can be traced along the east bank of a small brook for the distance of a mile. It is from 50 to 60 feet thick, very massive, and contains quartzite pebbles from 3 to 6 inches in diameter. Where weathered the pebbles fall out of the matrix readily and show little or no dynamic metamorphism. The resemblance of this bed to the conglomerates of the Dighton group is very striking, and the bed may be tentatively considered the equivalent of the coarse conglomerate which occurs at the base of this group. It is so represented on the map.

The strata in the northern part of Seekonk turn northeast, and then due east and pass into Rehoboth, and so continue on to the tract mapped on the Taunton quadrangle. Very good exposures may be seen along the road about half a mile north of the head of Wolf Plain Brook. A coarse conglomerate north of the road in the edge of the woods is probably the continuation of the Seekonk conglomerate. It is overlain by sandstones and pebble beds which dip from 5° to 10° S.

The strata just described in Seekonk and in the northern part of Rehoboth, as shown on the Providence quadrangle, form the western part of a broad, square-ended syncline. About 3 miles south of the point where the Seekonk beds turn from northerly to easterly strikes they again strike eastward to make the southern side of the Great Meadow Hill syncline. Some minor folding appears between this point and Great Rock.

The southern part of Seekonk and Rehoboth is heavily drift covered, and outcrops are from 2 to 3 miles apart and not in sufficient number to give much value to the interpretation of the structure in this part of the field. About 2 miles south-southeast from the Davis Carpenter place a coarse conglomerate striking E.-W and dipping 80° N. comes in, over-

lying sandstones, indicating the abrupt turning of the strata eastward in the manner above referred to. Half a mile east and a little north of this outcrop, coarse pebbly grits dip gently S., indicating minor folds in this part of the field. Whether these exposures are reappearances of the Seekonk conglomerate and the associated thick sandstones is an open question. The general structure of the area would place the strata at the top of the Seekonk beds, and they are so indicated on the map.

Three miles due south of these outcrops are two isolated outcrops of gray and locally pebbly sandstone. The westerly one forms a low roche moutonnée on the land of Mr. Fred. T. Haskins; the eastern one, at the corner of the road, forms a massive knob 25 feet high. In the southeastern corner of the area represented on the Providence atlas sheet, in Swansea and partly in Barrington, Rhode Island, are outcrops of sandstone and conglomerate striking NNE.-SSW. and standing at high inclinations. At a few points the sandstones rise into knobs 30 feet high. A slaty cleavage is sometimes shown striking N. 56° W. and dipping N. Where pebbles occur they vary from half an inch to an inch in diameter. Between these beds and the last-described outcrops there lies the broad, shallow valley of the Warren River, partly drift filled and indicating the existence of some underlying, softer, valley-making beds along the median or anticlinal line between the Dighton and Taunton synclines.

BEDS NORTH OF THE TENMILE RIVER IN ATTLEBORO.

Thus far there have been described a series of strata continuous along their strikes on the south and east of the Tenmile River and along the Providence River, and a section upward to the coarse conglomerates of the Dighton group. Similar strata are less perfectly shown in Attleboro north of the Tenmile River and the Perrins anticline. On the south side of the stream and the axis named the beds dip gently southward, but wherever they appear on the north they have steep northerly dips. On the grounds of the American Millenium Association, near Hebronville, a well was sunk 10 feet in drift and 20 feet into a gritty sandstone, but the first ledges of diagnostic value appear along the banks of the Tenmile River in Dodgeville, where sandstones are seen dipping steeply northward. Half a mile west of the railroad station, and over 2,000 feet below the coarse conglomerate in the Attleboro syncline, is an isolated exposure of coarse gray

conglomerate dipping 70° N. About 60 feet of beds are exposed, showing alternations with sandstone and slate. The pebbles of the conglomerate are granitite, quartzite, and quartz, and range up to 5 inches in diameter. This bed occupies a stratigraphic position on the north side of the Perrins anticline roughly corresponding to that of the Seekonk conglomerate on the south side of the axis, and raises the question whether the Seekonk conglomerate is the coarse conglomerate elsewhere found at the base of the Dighton group or a lower conglomerate comprised within the Seekonk beds proper. Westward and eastward for many miles no rocks are exposed along this northern strike line.

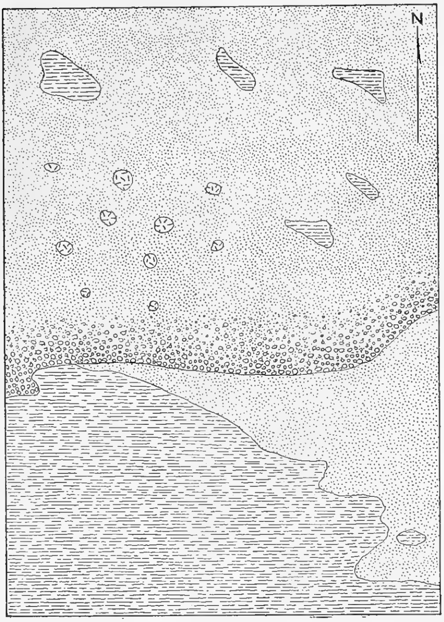
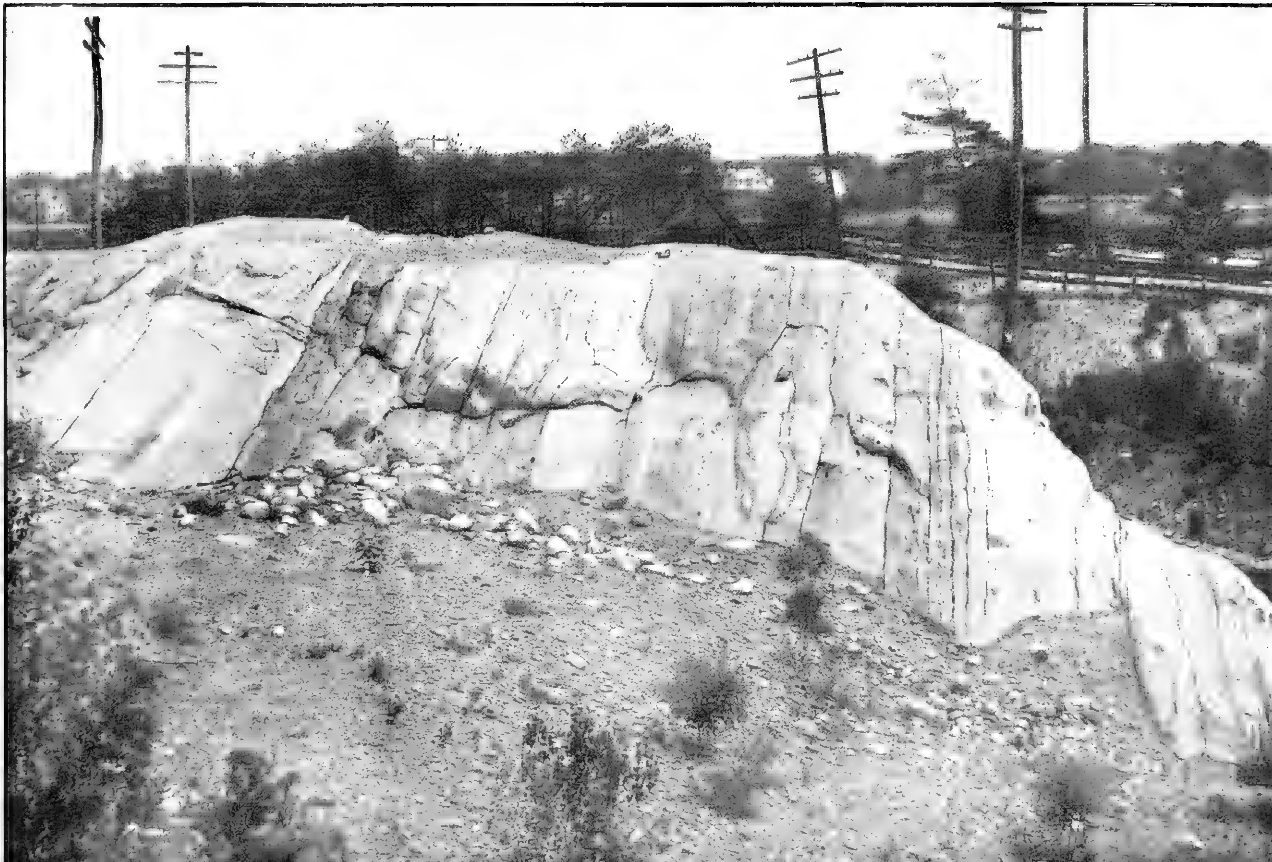


Fig. 24.—Contemporaneous erosion, with unconformity, in the Carboniferous at Attleboro, Massachusetts. The pebbles shown in the upper part of the diagram are identical with the red slate in the lower part.

Somewhat higher up in the section, and over a mile northeast of the last-named outcrop, there are exposed, along the Old Colony Railroad tracks at Thatcher road bridge, 1 mile south-southwest of Attleboro station, about 40 feet of coarse, gray, gritty, and often conglomeratic sandstones exhibiting cross bedding and marked local or contemporaneous erosion. A bed of fine sandstone 20 feet thick was excavated, evidently by a river, to the underlying coarse pebbly beds, and then the area was covered up with coarse sands. This feature can be relied upon to show that the northern face of the strata was originally uppermost. The beds stand at high angles, dipping north.

Contact of red and gray beds, with local unconformity.—Crossing northward over a few feet of covered beds, we find a glaciated exposure by the roadside exhib-



VERTICAL CARBONIFEROUS SANDSTONES SOUTHWEST OF ATTLEBORO, MASSACHUSETTS LOOKING EAST.

CARBONIFEROUS CONGLOMERATE WITH MEDIUM-SIZED PEBBLES, ATTLEBORO, MASSACHUSETTS. VIEW LOOKING EAST OF NORTH.

Pebbles of red quartz, granite, slate, and quartzite.

iting a clear instance of local erosion following the deposition of red shales and preceding the deposition of more gray beds. Angular fragments of the red shale occur in the overlying gray beds, completing the evidence of unconformity at this point. The structure is indicated in the accompanying diagram of the locality (fig. 24).

A few feet stratigraphically below this level of contemporaneous erosion and a few yards westward in the vertical beds is the well-marked unconformity before mentioned. It is partly concealed by glacial gravels, but shows the cutting off on the west of about 20 feet of fine sandstones. The continuation of these beds on the west of this ancient channel of erosion is not exposed. The excavation or channel thus formed was subsequently filled with coarse sands, which also mantle over the fine sandstones to the eastward of the ancient stream bank.

The phenomena of this horizon indicate clearly the fluviatile nature of the sedimentation in this portion of the Carboniferous area. The deposits may have accumulated near sea level, but under conditions in which the streams were given steep gradients and large supplies of freshly eroded detritus of granite and quartzite, as if in some mountainous lake or bhábar district, such as that at the southern base of the Himalayas in India.

Red shales.—The red shales which now succeed the gray beds can be traced southwestward along the southern side of the Attleboro syncline. They alternate with gray sandstones, and where most distinctly shown have an ascertained thickness of 60 feet. Strata which exhibit a reddish color, however, continue upward in the section nearly to the base of the coarse conglomerate which forms the nose of the syncline. On the land of Mr. Joseph Fisher the following section is exposed:

Section near Attleboro, on Thatcher road.

	Feet.
Red shales and sandstones with gray sandstone interlaminated (top not seen)	22
Sandstone, gray	8
Sandstones, grayish-green (quarried)	52

The red sandstones contain annelid borings.

A little higher up than these red strata is a coarse conglomerate. Still higher up are fine conglomerates with pebbles of quartzite, granitite, and quartz. (See Pl. VIII.) The quartz is often deeply stained with iron oxide. Overlying these fine conglomerates are the reddish-tinged strata mentioned

above. At the eastern end of the syncline shown upon the map these beds may be seen turning northward and westward, with cross bedding plainly showing the original top of the strata. The use of cross bedding in determining the original position of strata depends upon the fact that where the inclined "fore set" layers are somewhat eroded the succeeding layers rest upon their truncated edges. The evidence thus derived from the cross bedding confirms the view that these beds are on the northern side of an anticline whose axis is shown in the Perrins cut.

These beds immediately below the coarse conglomerate also exhibit worm burrows, trails, and current marks (see Pl. IX), and, what is even more remarkable for this basin, the imprint of raindrops on an ancient beach or exposed flat. (See Pl. X.)

Raindrop imprints.—The locality exhibiting raindrop imprints is about one-half mile southwest of the crossroads at the canoe end of the Attleboro syncline, where the reddish micaceous sandstones below the Dighton conglomerate are exposed in a quarry. The surface of one layer is current-marked, with the steep fronts of the irregular ridges facing southeast when oriented with reference to the horizontal position, the beds now standing vertical at this locality. Over the current marks are the imprints of raindrops. These records of former meteorological conditions are on the northern and upper face of the vertical bed, and the stratum is on the south side of the axis of the syncline, a position in every respect consistent with the interpretation of the stratigraphic succession advocated in this report. This is, so far as I am aware, the only locality in the basin in which raindrop imprints may be seen in situ. The preservation of the record at this locality, where the beds have been pushed up into a vertical attitude, indicates that at least locally the dynamic metamorphism in the Rhode Island coal field has not gone so far as has been commonly believed. The condition of the imprints in this case further shows that in the folding of the strata there was, at least on this horizon, little or no widespread shearing of layer over layer, an action which in other localities is

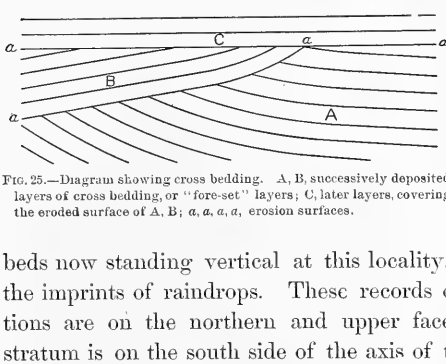
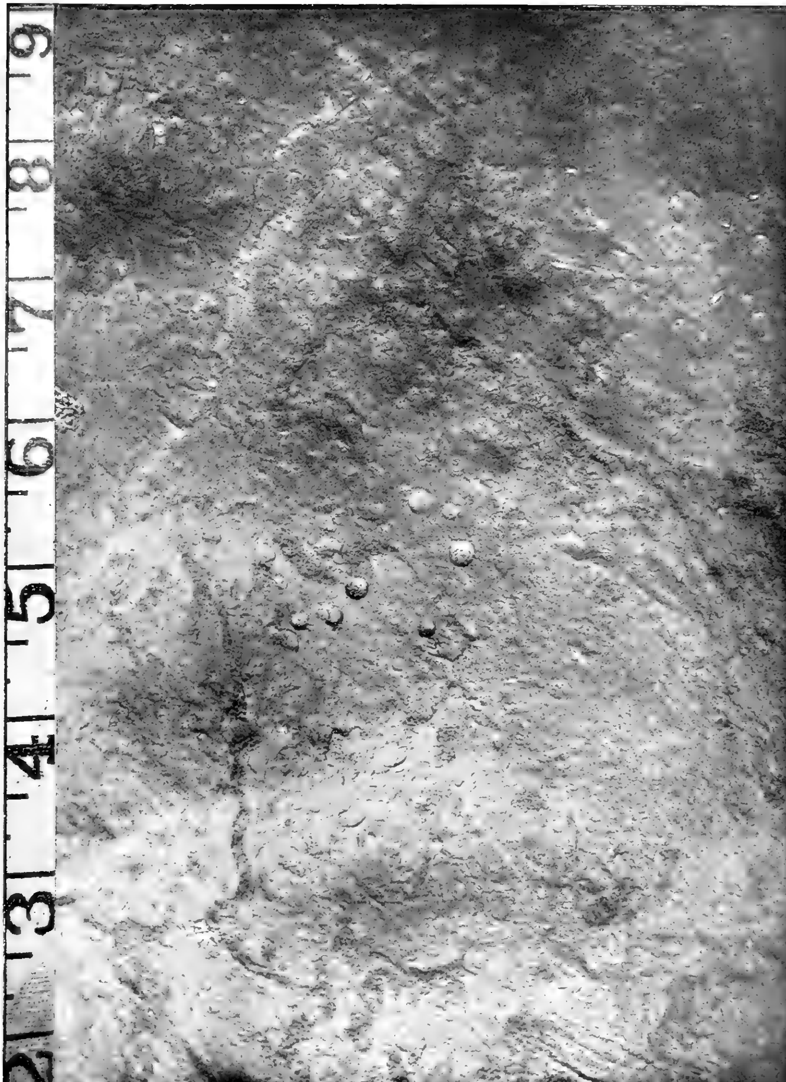


Fig. 25.—Diagram showing cross bedding. A, B, successively deposited layers of cross bedding, or "fore-set" layers; C, later layers, covering the eroded surface of A, B; *a, a, a, a,* erosion surfaces.

RIPPLE-MARK ON SANDSTONES IN THE SOUTH FLANK OF THE ATTLEBORO SYNCLINE. LOOKING SOUTH.

Strike of beds, east; dip, 85° N. Scale in inches.



RAINDROP IMPRINTS AND WORM BURROWS ON VERTICAL CARBONIFEROUS STRATA, SOUTH FLANK OF ATTLEBORO SYNCLINE

Looking south. Scale in inches

usually marked by minute slickensides or the appearance of a "grain" running up and down the dip in the direction of the shearing movement. A slickensided fault plane in the bedding is shown at this locality.

Attleboro syncline.—One of the few points in the basin where the structure and superposition of beds are exhibited within a small area and in a satisfactory manner is midway between Attleboro and South Attleboro, in the elevation known as Ides Hill, lying between the Tenmile River and Fourmile Brook. In this area of not over 2 square miles there is a well-defined syncline in the Carboniferous strata, involving in the axis a thick section of coarse compound conglomerates, immediately overlying the highest of the rocks just described as lying north of the Perrins anticline. The nose of this syncline is formed by the conglomerate, which stands up as a low bluff at the crossroads $1\frac{1}{2}$ miles southwest from the station in Attleboro. (See Pl. XII.) The beds on the south side are vertical, and can be traced along the entire area above described. The corresponding strata on the northern side of the syncline are not so well exhibited. Near the crossroads just mentioned, conglomerates exhibit a southward dip of about 45°, and about 2 miles west, near Fourmile Brook, steep southerly dips are again seen in conglomerate. Northward to the edge of the Wamsutta series the structure is not exposed.

It seems probable that this group of conglomerates belongs on the horizon of the Dighton group, at the top of the Coal Measures in this basin (see p. 184), the red rocks of the Wamsutta group on the north having been brought up against these higher beds by dislocation.

Eastward of Attleboro and northward to the limits of the Providence quadrangle in the directions named, the surface is too thickly covered with glacial drift to make an interpretation of the under geology possible. The area is, I confidently believe, underlain by Carboniferous strata, abundant fragments of grayish conglomerates, grits, and sandstones occurring in the drift. Judging from these erratics, which have not traveled far, conglomerates and the finer-grained rocks occur in this tract. The red Wamsutta beds may also be expected to reappear in this eastern area, folded in with the gray rocks. Bowlders of this formation appear in the glacial drift northeast of Attleboro.

Westward of the line of section above described there are two or three well-marked knobs of sandstone and conglomerate on the east of the road

from South Attleboro to Hebronville. These beds probably represent the horizon of the Seekonk group on the north side of the Perrins anticline.

BLAKE HILL FAULT BLOCK.

The gray Carboniferous strata west of Plainville in Blake Hill exhibit several small monoclinal ridges of hard sandstone and quartzose conglomerate with interbedded shales, here and there containing casts of calamites and rarely other members of the Carboniferous flora. The most prominent of these ridges has received the name of "Goat Rock." A detailed measurement of the strata exposed in this bluff above the talus has been made by Mr. F. C. Schrader, to illustrate the character of the barren beds in this section:

Section of Goat Rock Cliff.

	Feet.	Inches.
Gray sandstone (at top)		9
Conglomerate, gray, coarse, with irregular partings of black slate about 2 feet from base	12	0
Shale, dark and slaty		8.5
Sandstone, gray, varying to a pebbly grit	1	4
Shale, dark and slaty		2
Sandstone, gray, with a few small pebbles in middle of the layer		11.5
Grit, fine, pebbly		3.5
Sandstone, grading downward from above		4
Sandstone, hard, fine grained		5.5
Shale, slaty, with plant stems	1	10
Sandstone, very fine grained	1	1.5
Shale, slaty		2
Grit, gray and finely conglomeratic		11.50
Shale, dark slaty		11
Sandstone and grit		8.50
Conglomerate, gray, gritty, and grading upward into next above		7
Sandstone, gray		2.5
Shale, slaty		7.5
Sandstone, bluish gray		11
Shale, black and slaty, with plant stems		3
Conglomerate, fine, gray, and gritty	1	8
Shale, dark and slaty, a mere layer		.2
Sandstone, gray		5
Shale, dark, slaty		.2
Sandstone, gray		.5

PLAINVILLE VALLEY, WRENTHAM, MASSACHUSETTS.

Looking east of north from edge of Black Hill fault block. Terraces of gently westward-dipping Coal Measures in foreground; vertical Carboniferous beds traversing floor of valley and background.

Section of Goat Rock Cliff—Continued.

	Feet.	Inches.
Shale, dark, slaty, a mere layer		.2
Sandstone, gray		5.5
Shale, with fossils, grading into sandstone		4
Sandstone, slaty		6.5
Slate		.75
Sandstone, a hard gray rock		4.5
Grit, gray and hard		9
Sandstone, gray, with plant stems, and traces of fine-grained dark slate		2.5
Sandstone, subslaty, with plant stems		1
Sandstone, fine grained, gray		6
Shale, dark, slaty, trace		.25
Sandstone, gray		3
Shale, dark reddish and slaty, with plant stems		.75
Conglomerate, gray and gritty, rather fine		2.5
Shale, black and slaty, with plant stems		8.5
Sandstone, fine grained, dark gray, and in places gritty		.4
Shale, dark and slaty		5
Sandstone, gray		10
Conglomerate, fine and gritty	2+	
Talus of covered strata	30	0

A noticeable feature in this section is the frequent alternation from sandstone to shales within a very limited thickness. The coarse conglomerate forming the crest of the ridge exhibits a variety of pebbles, as regards both origin and secondary structures. The pebbles are chiefly a fine-grained whitish quartzite, often presenting slaty cleavage, the discordant direction of which structure in juxtaposed pebbles is evidence of mountain-building in this geological province prior to the Carboniferous period and subsequent to the formation of the quartzite, which is probably of lower Cambrian age.

Fossils.—The fossils found in place in this section are mainly imperfect stems of calamites. In the drift in the vicinity of Goat Rock there have also been found two species of determinative value, viz: *Alethropteris* and *Sigillaria volzii* Bt.

The latter plant is stated by Lesquereux[1] to be rare in the Coal Measures of America, one specimen being seen by him from the Plymouth F vein in Pennsylvania, a horizon near the top of the anthracite field.

[1] Coal Flora, p. 492, Pl. LXXII, fig. 11.

Dr. A. F. Foerste also found in the sandstones of this area calamite trunks 6 inches in diameter.

Coal.—A bed of coal said to be 6 feet thick was met with in digging a well on the land of Mr. Charles P. Simpson in the autumn of 1890. This locality is in the southern part of Wrentham, near the Attleboro boundary line and on the eastern face of Blake Hill block. (See Pl. XI.) The well is reported to have passed through the following strata:

Section of well near Attleboro, Massachusetts.

	Feet.
Sandstone	24
Coal, anthracite	6
"Flinty sand rock," thickness unknown.	

Westwardly, gray conglomerates overlie the coal section, and eastwardly sandstones crop out from beneath it. It is shown by these latter beds that the dip is here gentle to the southwest. The outcrop of the coal bed is about 260 feet above sea level and from 20 to 25 feet above the level of the pond in the northwest part of North Attleboro. Southward of this locality the Blake Hill block is probably cut off by a fault, as basal arkoses come in at the distance of half a mile along the strike line. Northwestward along the strike the conditions appear favorable for exploiting this bed along the western side of the Plainville Valley.

Yet farther eastward, and lower down, micaceous sandstones crop out along the roadside and contain impressions of trees of small size. At other points along the southern edge of the Blake Hill block the waste from highly carbonaceous shales occurs in the glacial drift.

This block of strata dips throughout to the westward, the dip increasing from near horizontality along the eastern boundary at Plainville to 30° and 45° along the western, ill-defined margin. The western contact is apparently made with the red Wamsutta series. It appears as if this block, over a mile in width and about 3 miles in length, had been thrust into its relatively undisturbed position, while the strata around it on the east, south, and west, as well as the beds beneath its eastern foot, had been thrown into steep folds and even overturned. It will be noted that the Blake Hill block lies north of and behind the Hoppin Hill granitite boss, around which the horseshoe fold of the Wamsutta is bent.

The stratigraphic position of the block can be only vaguely stated.

In succession and sediments it strongly resembles the beds which appear in East Providence and Seekonk in the middle portion of the coal-bearing series. The following is a more explicit account of the supposed faults which form the block:

Blake Hill thrust plane.—If a line be drawn parallel with the Walpole and Wrentham Railroad tracks at Plainville Station and a little west of the roadbed, it will follow closely the boundary between the nearly horizontal strata of the Blake Hill block on the west and the vertical strata of the country on the east (see Pl. XV), at the extreme western end of the Mansfield syncline. Opposite the Plainville Station this boundary line turns westward in the form of a small loop, inclosing several outcrops of the nearly vertical slaty strata which extend into the area of horizontal beds at the base of the Blake Hill block. It is evident from an inspection of the relations of these two sets of rocks, so sharply contrasted as regards attitude and secondary structures, that the vertical series passes westwardly beneath

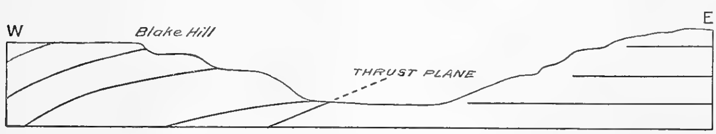


Fig. 26.—Geological section of Plainville Valley and thrust plane.

the Blake Hill block. Both sets of strata belong to the Coal Measures' but the evidence from fossils so far found is not sufficient to determine the relative position in the normal sequence of beds.

The Mansfield syncline is overturned between North Attleboro and Shepardsville, and the evidence in the field points to strong pressure exerted from the south and east upon this region. It was probably a result of this pressure that the Blake Hill block was thrust northward upon the edges of the broken Mansfield syncline. The position of the strata in the Blake Hill block in the system of folds before these were broken is hopelessly lost in the diverse structure of this troubled and now deeply eroded area.

Faults occur in the Blake Hill block west of the Plainville thrust plane and parallel with its outcrop. They are developed on a small scale. These faults are shown by two classes of facts: (1) The monoclinal ridges of hard sandstone and quartzose conglomerate which strike northwest are in

line with offsets in the Attleboro sandstone which bounds the block on the south. Goat Rock itself is the highest of these monoclinal ridges. (2) An earlier fault has brought the gray Carboniferous rocks down into a right-angled contact with the massive Attleboro sandstones. West of the Goat Rock section the red series is met with in a few outcrops and in a well on the northwest. There is reason to believe, therefore, that a fault bounds this block on the west so as to bring the red Wamsutta rocks up to the surface. (See fig. 16, p. 157.)

THE DIGHTON CONGLOMERATE GROUP.

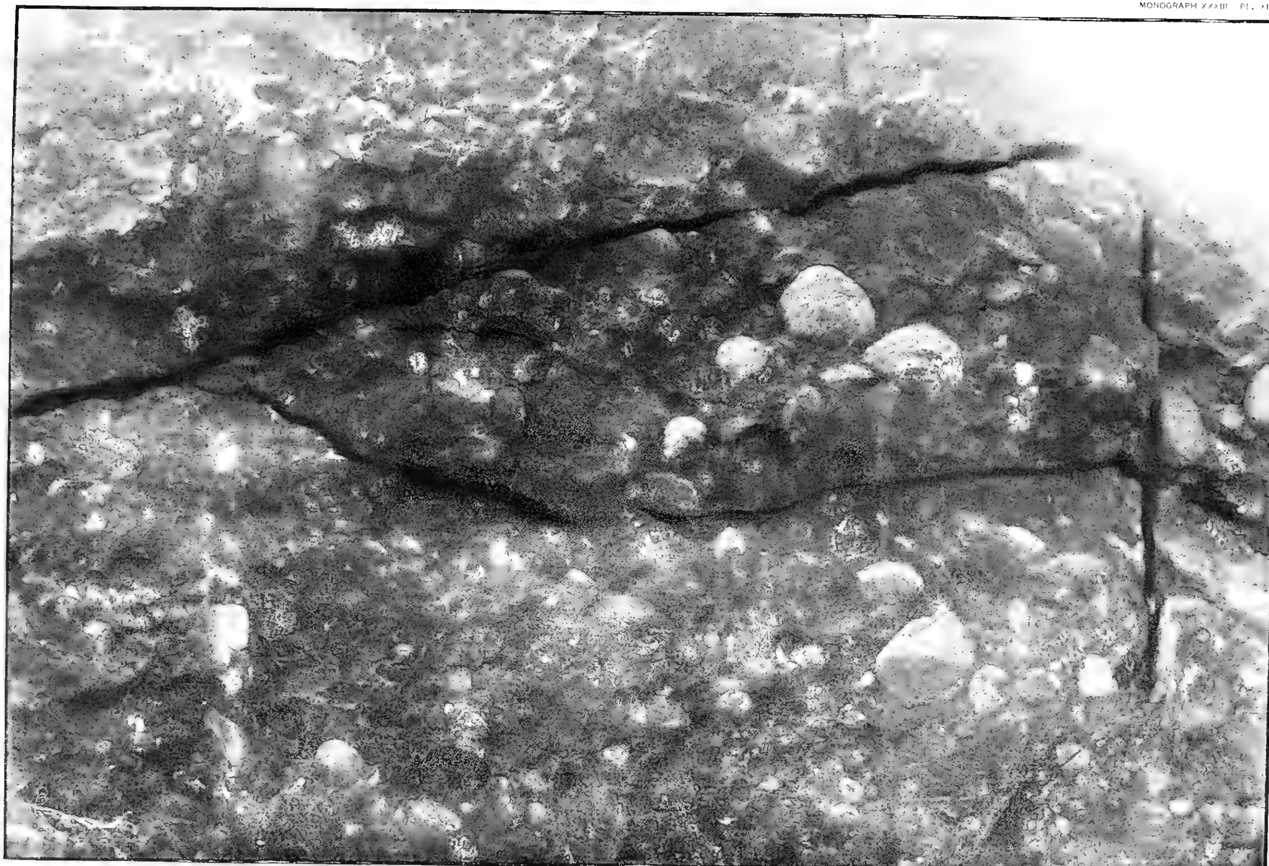
Roxbury conglomerate Edward Hitchcock: Final Report on Geology of Massachusetts, 1841, p. 538.

Reference has already been made to a coarse conglomerate bed believed to form the upper limit of the Coal Measures. The name Dighton conglomerate is here given to a group of coarse conglomerates, with alternations to sandstone, found as the highest members of the Carboniferous in Dighton, Somerset, and Swansea, in Massachusetts. The coarsest conglomerate bed is at the base of the formation. The rocks are better shown in Swansea than in Dighton, but the latter place being better known and more accessible for the purpose of examining these rocks, the latter name has been chosen. A few areas of coarse conglomerates elsewhere are referred to this horizon.

The Dighton conglomerate group attains where most developed a thickness of about 2,000 feet. Its Carboniferous age is not definitely proved, but it is assumed on the following grounds: The Dighton conglomerate directly overlies the Coal Measures. It is not derived from the erosion of underlying Carboniferous beds, but it contains larger pebbles of upper Cambrian quartzites than are known elsewhere in this field lower down in the Carboniferous section. It differs from other Carboniferous conglomerates only in that the fragments, being of larger size, demand for their transportation more vigorous processes than those previously active. The beds participated in the folding which closed the Carboniferous, and there is no known unconformity between the Dighton conglomerate and the subjacent strata. A typical outcrop of the coarse quartzite conglomerates of this Dighton group may be seen in the crossroads nearest the southwest base of Great Meadow Hill. One quartzite pebble, 8 inches long, contains the brachiopods of the upper Cambrian fauna.

TYPICAL BED OF THE COARSE DIGHTON CONGLOMERATES IN THE AXIS OF THE ATTLEBORO SYNCLINE

Looking south, at vertical bed in abandoned quarry



NEAR VIEW OF DIGHTON CONGLOMERATE IN THE ATTLEBORO SYNCLINE

Vertical bedding. Large pebbles 6 to 8 inches in diameter

In this northern part of the basin the several exposures of conglomerate referred to the Dighton group lie in the inner or upper part of synclines. This is true of the Great Rock area in Rehoboth, whence the rocks extend eastward to "Rocky Woods," near Taunton. Another, and perhaps the best area, is that of the Dighton syncline, extending from Dighton into Swansea. Another well-defined syncline in which these beds are found forms Ides Hill, west of Attleboro village. The coarse conglomerates at Purgatory and Paradise rocks, in synclines near Newport, resemble the rocks of this horizon.

The outcrops of coarse conglomerates at Swansea Factory and immediately west appear locally to strike northwest and dip north, indicating either that the great syncline is overturned southward or that there is here a local folding along the northern side of the major synclinal fold. Outcrops are too few to verify either hypothesis, but the high inclination of the observed strata southward below the Dighton group shows that the beds on this northern side of the synclinal axis stand at much higher angles than do those on the southern side. The Great Meadow Hill syncline is nearly symmetrical, but the Attleboro syncline on the north is unsymmetrical, with vertical dips on the south side of the axis.

The Dighton conglomerate is composed mainly of grayish and greenish quartzite pebbles in the southern areas; toward the north, as in the Attleboro area, it is equally rich in granitic pebbles. The amount of quartzite in this group must represent several hundred feet of strata stripped off the adjacent country in Carboniferous times. Many of the pebbles are fossiliferous, carrying the upper Cambrian fauna already described. The pebbles vary in size from a fraction of an inch to rounded waterworn cobbles a foot in diameter. The reduction to spheroidal shapes apparently indicates their passage through the surf line on a beach. (See Pl. XIII.)

In many sections the pebbles are packed together with the pellmell structure of glacial till; the paste is often earthy and ferruginous, and when slightly attacked by weathering allows the pebbles to roll out; in other sections pebbles and paste are thoroughly cemented, so that the rock breaks up only along joints.

Now and then a pebble shows a joint recess where the rolling action did not continue long enough to reduce it to the form characteristic

of wear on a beach. The frequency with which this occurs in the larger pebbles suggests that when submitted to the action of the waves the bits were angular joint blocks, such as quartzites afford when broken out of a cliff. (See photograph of one of these joint niches in pebbles, Pl. XIV.) Here and there an indented pebble may be seen.

The Dighton group of conglomerates being the highest member in this basin, the areas in which it occurs are, owing to the deep erosion of the basin, somewhat removed from the present margin. The distance is generally from 3 to 4 miles.

The topography of these conglomerate areas is bolder and more rugged than that of the other rocks in the basin outside of the Wamsutta series. The formation abounds in rounded, bare, rocky knobs, with steep vertical bluffs facing outward from the synclinal axis over the area of the Seekonk sandstones, again overlooking recesses in the formation itself. Long rocky ridges also abound, as in Dighton, Taunton, and Attleboro, now generally given over to woods on account of the scarcity and infertility of the soil and the general unsuitableness of the surface to agriculture.

The conglomerate masses attain elevations of 150 to 180 feet above sea level, or of 80 to 100 feet above the surrounding level. In Swansea the conglomerate ridges rise to 160 feet; in Dighton, to 180; and in Attleboro, also to 180. Near Taunton, the Rocky Woods attain an elevation of 160 feet. This level, indicated by the elevation of the conglomerate ridges, is somewhere near that of the Jura-Cretaceous peneplain were it extended eastwardly over the Carboniferous area. The excavation of the strata below this level must be attributed to erosion in the Tertiary period.

These conglomerate areas contain the headwaters of numerous brooks, but several of the larger streams in the southern part of the field flow across them, evidently from original courses which have been superposed on these hard rocks.

It remains to be determined whether there is an unconformity between the Dighton conglomerates and the subjacent Seekonk group. It is to be expected that even within the same geological period such discordances would exist where currents were developed strong enough to urge cobbles a foot or more in diameter out over an alluvial plain like that formed of the Coal Measures. The original thickness of the group is also a matter for further investigation. Were there higher Coal Measures in this area? And

SELECTED WATERWORN, INDENTED, AND PRESSURE-STRIATED PEBBLES FROM DIGHTON CONGLOMERATE IN ATTLEBORO SYNCLINE

[illegible] Massachusetts.

VERTICAL CARBONIFEROUS SANDSTONES, PLAINVILLE, MASSACHUSETTS

Three-fourths of a mile north-northwest from railroad station, looking southwest toward wooded escarpment of Blake Hill fault block

did Permian or later strata overlie them? There is a chance that in the center of some one of these synclinal areas higher beds than have here been recognized may be discovered. It is indeed possible that the whole of the Dighton series is of Permian age.

The contemporaneous flora and fauna of the conglomerate are as yet practically unknown. The brachiopods and worm burrows reported in the quartzite pebbles belong to the upper Cambrian fauna. (See p. 109.)

EXTENSION OF THE COAL MEASURES NORTH AND EAST OF TAUNTON.

Having described a typical area of the Coal Measures and the overlying conglomerates in a part of the basin where evidence of their structural relations can be had, it is now purposed to describe the eastern extension of these rocks, where the structure is less well understood. For convenience, the order of presentation which is suggested by the mapping of this portion of the field in sheets of the atlas folio will be followed, for the reason that within the limits of these maps, comprising the Dedham, Abington, Middleboro, and a part of the Taunton quadrangles, the exposures of strata are too few in number and extent to permit any systematic account of the stratigraphy. These rocks have been described with more fullness than their importance apparently deserves, partly for the reason that they have not been heretofore described, and partly because they are the sole indications of the under geology of the eastern part of the Carboniferous field.

DEDHAM QUADRANGLE.

The Carboniferous rocks of the main basin cover the larger part of the southern third of this quadrangle. After we pass southward and geologically above the rocks immediately along the border, outcrops are too few to give more than a very general view of the stratigraphy. The Coal Measures are present in Mansfield and West Bridgewater, and probably underlie the intermediate towns. The surface, outside of the glacial sand plains, is strewn with flaggy micaceous and feldspathic sandstones suggesting arkoses, which agree in character with some of the outcrops. A few conglomerate bowlders of the gray series occur, but never in the abundance which characterizes the proximity of the coarse Dighton group in other parts of the field. There is also absent the hilly and roughened topography which accompanies these latter beds when they occur in

synclinal areas, and it is evident that these upper portions of the Carboniferous have disappeared by erosion from this northern field. The relatively gentle dips along this margin, together with the observed great thickness of the formation where fully developed, would carry the outcrop of the uppermost beds several miles south of the border and out of the Dedham quadrangle.

The structure of the strata in this area, so far as it can be made out from observed outcrops, is mainly synclinal. The axis of this fold passes approximately through Mansfield Junction and South Easton; or, in general terms, lies at a distance of from 2 to 3 miles from the northern border. The trough is broad and shallow toward Brockton, but its sides steepen westward toward Mansfield, and between North Attleboro and the border it is much compressed, and the folded strata are finally lost to view beneath the block at Blake Hill. Its general features in the Mansfield area are shown in fig. 27, on p. 190. The following observations set forth the evidence in typical areas, about Mansfield and Bridgewater:

MANSFIELD AREA.

There are no surface exposures in the immediate vicinity of the West Mansfield coal mines, the rock having been found in digging a well. The lowest strata of the Carboniferous appear nearly 4 miles north of the coal mines, dipping gently off to the south from the hornblendic granitite of the Wrentham-Hingham uplift. The basal arkoses and grits, described with the Wamsutta series (pp. 135–139), form conspicuous ledges on the southern face of Foolish Hill, in Foxboro. The Wamsutta series has here a possible thickness of 1,000 feet. It is succeeded on the south by quartz pebble and quartzite conglomerates and gray sandstones, forming glaciated ledges scarcely above the general surface of the glacial drift. Southward from Foolish Hill toward Mansfield Junction, beds of sandstone and conglomerates appear, dipping about 25° S. A roche moutonnée gives the following section from the top:

Section of a roche moutonnée in the Mansfield area.

	Feet.	In.
5. Sandstone, with layers of slate pebble conglomerate	6	6
4. Sandstone	3	6
3. Conglomerate, with slate pebbles	1	0
2. Sandstone	5	0
1. Conglomerate, base not seen	10	0

GENERAL VIEW OF SURFACE AT WEST MANSFIELD, MASSACHUSETTS.

Showing glacial plain covering over the Coal Measures. Site of old coal mine in Groves Lane behind stone fence on the left. Looking northwest (1895)

These beds dip to the S. 30°; the cleavage dips N. 50°. The exposure is noteworthy in exhibiting preexisting dark slates, broken up and deposited at this time. The slate fragments are angular and conspicuous elements in the layers in which they occur. They vary in length from 3 to 4 inches and in thickness from 1 to 2 inches. The attitude of the fragments and the unruptured state of the stratum, except for joints and cleavage, preclude the formation of the slate fragments by the disruption in post-Carboniferous times of an original argillaceous layer. For similar reasons, the fragments are not to be regarded as contemporaneous pockets of argillaceous sediments. In the absence of contained fossils or other evidence of the age of these pebbles, there is doubt whether they are fragments of the subjacent Carboniferous shales or are detached pieces of the dark slates of middle Cambrian age, remnants of which occur at Braintree, in the Boston Basin. The not infrequent occurrence of signs of contemporaneous erosion in the Carboniferous beds in the basin leads me to conclude that the conglomerates are of the class called "intraformational" by Walcott.[1] I have already described a limited occurrence of this kind at the contact of red and gray beds in Attleboro. North and east of the junction at Mansfield occur a few outcrops of conglomerate with small pebbles and associated sandstones. At the junction are two exposures of grayish feldspathic sandstone—massive beds, like the typical sandstone ridges of the Seekonk formation. The knob west of the railroad carries the flattened impression of a large tree, and the rock in the railroad cut is much shattered.

One and a half miles south of the Junction is a locality where coal was formerly mined (see Pl. XVI). In the absence of surface exposures, and because of the abandonment of the old shafts, it is impossible to get other data concerning the structure at this locality than those furnished by the records of earlier surveys and by one recent boring. From the Massachusetts report[2] it would appear that the beds here strike NW.-SE. and dip NE. from 30° to 35°, or as high as 45°, and in another place that the strike of the beds is NE.-SW.; but the observation of C. T. Jackson,[3] that the "strata between which the coal beds are included run quite uniformly

[1] C. D. Walcott: Bull. Geol. Soc. Am., Vol. V, 1894, pp. 191–198; Bull. U. S. Geol. Survey No. 134, 1896, pp. 34–40.

[2] Final Report on the Geology of Massachusetts, 1841, pp. 133, 540.

[3] Geology of Rhode Island, 1840, p. 107.

ENE.–WSW., and dip to the NNW. 53°," is, in my opinion, approximately accurate.

Both C. T. Jackson and Edward Hitchcock agree in giving a northerly dip to the rocks at this point, from which it is evident that the Mansfield coal beds occur on the south flank of a syncline, and may be expected to reappear on the northern side of the axis or in the vicinity of the Junction. The probabilities are, however, that the sediments in this direction become coarser as the shore line is approached, and that the coal beds either thin or entirely disappear. The coal in Foxboro reported by Edward Hitchcock, nevertheless, may be a reappearance of the coal on the northern side of the axis.

One and a half miles south-southeast from West Mansfield Station, in the Taunton quadrangle, red and gray sandy slates occur with nearly vertical dips striking N. 64° E., indicating, along with other outcrops described in connection with that atlas sheet, the much steeper southern side of the syncline and the passage to the adjoining anticline. The accompanying section (fig. 27) represents the known and inferred portions of the structure through the Mansfield area:

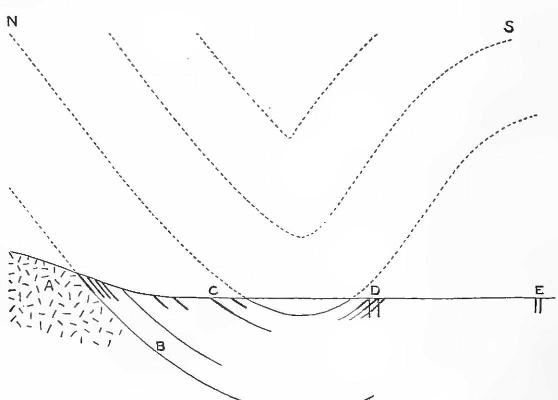


Fig. 27.—Section of the Mansfield Coal Measures. The lines represent observed beds and their underground extension A, Foolish Hill granitite; B, Wamsutta series; C, Mansfield Junction. D, West Mansfield mines. E, vertical strata south-southeast of last.

Analyses of two coals met with at depths of about 90 and 850 feet, respectively, in a boring put down near the old Hardon mine, have been

published by Dr. A. B. Emmons.[1] In the annexed table, analysis No. I is from the 90-foot coal, and No. II from the 850-foot bed.

Analyses of coals from the Mansfield area.

	I.	II.
Water	1.02	3.08
Volatile combustible	3.76	6.22
Carbon	74.24	79.68
Ash	20.97	11.02
	99.99	100.00
Sulphur	.56	
Fuel ratio $\left(\frac{\text{Carb.}}{\text{Vol. comb.}}\right)$	19.74	12.81

Thin sections from the core made in this boring, according to a manuscript report by Prof. Collier Cobb, showed that the amount of metamorphism varies with the depth, being greater at the bottom than near the surface.

Flora of the Mansfield section.—The following plants have been reported from the shales at Mansfield:

Prof. Edward Hitchcock[2] figured forms referable to the genera—

Calamites.
Sphenophyllum.
Asterophyllites.
Annularia.
Pecopteris.
Sigillaria.
Cordaites (a form close to *C. robbii.*)

Leo Lesquereux[3] has described:

Sphenopteris salisburyi (n. s.).
Rhacophyllum adnascens.
Pseudopecopteris irregularis.

Teschemacher[4] described and named several forms, some of which are of doubtful identification:

Neuropteris angustifolia.
 heterophylla.
Pecopteris loschii.
 borealis.
Pecopteris gigantea.
Sphenophyllum truncatum (said to be unknown except to Teschemacher).
Sphenophyllum dentatum=erasum.

[1] Trans. Am. Inst. Min. Eng., Vol. XIII, 1885, p. 515.
[2] Final Report on the Geology of Massachusets, 1841.
[3] Providence Franklin Society Report on the Geology of Rhode Island, 1887.
[4] Boston Jour. Nat. Hist., Vol. V, 1846, pp. 370–385.

BRIDGEWATER AREA.

The available exposures from Brockton southward through the Bridgewaters indicate a broad syncline with low dips, and hence a much more shallow trough than that near Mansfield. Southerly dips are found in out crops from the granitites north of Brockton for a mile or more to the south of that city. At Cochesett, and thence southward, northerly dips are encountered as far as the northern part of the Taunton and Middleboro quadrangles, in the vicinity of Scotland, about 3 miles south of the limits of the Dedham quadrangle.

Overlying the chocolate-colored sandstones at Brockton, described under the head of the Wamsutta group, occur arenaceous and argillaceous strata of slaty structure. Exposures of a bluish coarse sandstone have been made in opening new highways northwest of Campello, at the corner of Adams and Center streets. One and a half miles south-southeast from this locality, on the west side of Salisbury Plain River, bluish-green slates form a small outcrop. The cleavage is E.–W., and dips 45° N., the prevailing direction and steep dip along the northern border. Bowlders of grayish sandstone occur in the vicinity.

Going southward across the strike, the next exposure is in the railway cut a mile east of Cochesett Station. The strata here dip from 5° to 10° N., and afford the following section from the top downward:

Section east of Cochesett Station.

	Feet.
3. Conglomerate; pebbles of quartzite and smoky quartz	10
2. Sandstone and arkose, gray	10
1. Shale, blue and compact	10

A thrust plane, with slickensides trending N.–S., was noted on one bed, and there are to be seen small vertical quartz veins containing cavities lined with botryoidal limonite.

About a mile south of the Cochesett exposure, coal is represented to have been found, in the area between the Hockamock and Town brooks.[1] The place of this bed would be at a depth of about 1,800 feet beneath the Cochesett section.

[1] Edward Hitchcock: Report, 1833, p. 277; Final Report, 1841, p. 129, also on geological map. C. H. Hitchcock: Geological map in Walling and Gray's Atlas of Massachusetts, 1871.

The extension along their strikes of the several strata thus obscurely exposed can not be traced with certainty more than a few rods. As in the Mansfield area, there are no indications of the higher beds of the Carboniferous section, so well exposed in the deep synclines of Dighton and Taunton. The beds for the most part appear to belong to the few hundred feet of Coal Measures coming in above the red Wamsutta series. Unless the Carboniferous formation thinned out in this direction, the post-Carboniferous erosion of beds of this age alone in this field must be measured as upward of 10,000 feet of strata.

ABINGTON QUADRANGLE.

In the southern part of this quadrangle more has not been possible than roughly to discriminate the lower reddish strata of the Wamsutta extension from the area occupied by the gray Carboniferous strata of the Coal Measures. The first-named series has already been described on page 143.

There are about a dozen exposures of the gray series of the Coal Measures known in this quadrangle. Beginning on the northwest, in Abington, the gray series is seen in a small outcrop about 1½ miles south from the granitite border. It is over 5 miles from this locality southward to the outcrops including Sachems Rock near the Satucket River, in the town of East Bridgewater.

Sachems Rock is a knob about 175 feet long and 20 feet high, composed of massive-bedded, somewhat altered sandstone with bands of small pebbles of white and smoky quartz, a fine-grained granitic rock, and a slate of undetermined origin. The attitude of the beds is nearly horizontal, dipping, if at all, to the north. There is a pronounced cleavage striking N. 77° W. The western side of the ledge has been opened for the purpose of quarrying. The smaller exposures to the east along the street are like the first, showing to the eye abundant minute scales of muscovite. The cleavage planes maintain the same direction, and dip steeply to the north.

These beds are on the southern side of the broad, shallow syncline which covers the southern part of the Dedham area, next north. They would come, in accordance with the supposed structure, low down in the Coal Measures.

In Hanover, half a mile east of Drinkwater River, and about 2,100

feet south of the northern border, is a probable outcrop of gray Carboniferous sandstone in the street; it may be a large bowlder. Bowlders of the same lithological texture are abundant upon the surface. Southward to the limits of the quadrangle no outcrops have been found.

Eastward, in the vicinity of Hanover Four Corners and near the eastern igneous border, several outcrops of the carbonaceous series appear. Beginning on the northeast, in South Scituate on the east bank of Third Herring Brook there is either a large bowlder or an outcrop of sandstone with bands of small pebbles. Southward, where the road from Hanover Four Corners to North Pembroke crosses North River, there are good exposures, forming a narrow defile through which the river escapes from a broad valley on the west to the wide channel extending beyond this cut to the sea. The strata are sandstone and arkose with coarse grits, bands of slate, and carbonaceous matter, striking in an east-west direction and standing at high angles. On the south side of the river, in August, 1889, there was found in a coaly seam the stem of a calamite.

One and a half miles farther up the North River, where it is crossed by the west road from the Corners to Pembroke, other exposures of the Carboniferous conglomerates and sandstones occur, on the south side of the stream. At the edge of the stream, in July, 1889, conglomerates and sandstones were exposed under a mill. The bedding was much obscured by joints. A few rods southward a blue compact sandstone is exposed, by the roadside, apparently overlying the above-named beds. Across the road and a few yards south of this cut a well was sunk, in July, 1889, through 10 feet of till into a dike of fine-grained, dark-colored diabase containing numerous inclusions of granitic quartz from one-eighth to one-half inch across, and a few pieces of feldspar. Angular fragments of red granitite also occur in the diabase.

Half a mile farther up the river the stream lays bare a section of closely jointed sandstones apparently dipping northward. In the bank above the carriage road there is much carbonaceous waste. In the road ascending the hill at the head of the westernmost of the three headwater branches of Swamp Brook, in Pembroke, black clays occur, which are also met with in excavations on the adjoining land. The relations of these deposits are very uncertain.

TAUNTON QUADRANGLE.

The eastern part of the area designated the Taunton quadrangle is nearly devoid of outcrops. In general it may be said that, except for a triangular area on the southeast equal to about one-ninth of the whole, this quadrangle is occupied by the rocks of the Carboniferous system. The strata which appear at the surface are mainly the harder conglomerates and sandstones, thrown into anticlines and synclines. Of these structures there are at least two well-defined sets in the western part of the quadrangle: the Dighton syncline, with coarse conglomerates, coming to a nose-like end at Dighton in Richmond Hill; and the Great Meadow Hill or Taunton syncline, with the coarse conglomerates of the "Rocky Woods," west of Taunton. Between these two great conglomerate areas lies the axis of an anticline which probably traverses the area eastward to Middleboro. On the northern side of the Rocky Woods tract is an anticlinal axis with nearly vertical strata, north of which lies the Mansfield syncline.

The deposits so far recognized range from the highest beds in the formation, including the Dighton conglomerates, downward toward the middle of the Coal Measures section, including members of the Seekonk and Tenmile River beds. The precise position of the lowest strata seen is not definitely known. The following notes pertain to important natural exposures of the strata and to artificial openings.

Red beds.—At one point in the northwestern part of the quadrangle, about 1½ miles southeast of West Mansfield Station, in the road on the west side of Hodges Brook, red slates are in contact with gray beds, striking N. 64° E., with nearly vertical dips. This is the only exposure of red beds known in this area, but whether they are an extension of the red slates in Attleboro or are a reappearance of the Wamsutta group, there is no means of deciding. The red slates in the drift south of this point afford plainly marked flattened impressions of calamites.

Outcrops in Norton.—Midway between Norton village and the southwestern arm of the Norton reservoir is a low outcrop exposing about 100 feet of conglomerates, sandstones, and slates. The strike here is nearly NE.–SW. The conglomerate is composed of quartz, quartzite, and granitic pebbles varying from half an inch to 3 or 4 inches in diameter. These beds can be traced eastward for a quarter of a mile. Unless they are overturned

they overlie the following section, which is separated from them by several hundred feet of concealed beds.

Near the southeastern end of the Norton reservoir are broad exposures of slaty arenaceous strata striking N. 54° E. and dipping 75° S. The following paced measurements give the succession, from south to north:

Section in Norton.

	Feet.
1. Slate	3
2. Sandstone	39
3. Slate	5
4. Sandstone	2
5. Slate	12
6. Sandstone	8
7. Slate	1
8. Sandstone	27
9. Slate	9
10. Sandstone	18
11. Slate	48
12. Sandstone	22
13. Slate	2
14. Sandstone	34

The prevailing character of this section is similar to that of the beds in the same anticlinal fold to the westward in Attleboro. The absence of carbonaceous matter in the exposed sections is noteworthy.

A few isolated outcrops in the village of Norton display beds of conglomerate and grits, with variable dips. At one point the inclination is as low as 50° N. The general structure of the belt of rocks through Norton is probably anticlinal, for the Mansfield and Bridgewater synclinal trough lies on the north and the Great Meadow Hill syncline is well marked on the south.

Winneconnet ledges.—From 2 to 3 miles northeast of the exposures in Norton occurs the Winneconnet section, on the east bank of Mulberry Meadow Brook. There are here exposed upward of 200 feet of soft slaty rock of an arenaceous and often gritty texture. The cleavage dips west, and its strike is N. 49° E., but the dip of the bedding is not easily determined. One and a half miles northwest of this locality is another exposure of similar slates. In both places the surface of the rock weathers into pear-shaped and rounded cavities, recalling the weathering of the ottrelitic

schists along the shores of Narragansett Bay. It is probable that the metamorphism of the beds along this anticlinal line has been greater than elsewhere in the eastern part of the basin, or that lower beds are here exposed. (See fig. 6, p. 120, locality B.)

Eastward, outcrops appear in the vicinity of Scotland. About three-fourths of a mile south of the town pebbly sandstones strike nearly E.–W. and dip about 20° N., forming a low monoclinal ridge with an escarpment facing the south.

Beginning the description on the western border of the quadrangle again, the beds on the south side of this broad anticline are represented by a few exposures. The best of these is at a point near the western margin, on the west side of Chartley Brook, about 2 miles south of the Attleboro branch of the Old Colony Railroad. An old quarry here occurs in a knob of the gray Carboniferous. The strike is N. 69° E., the dip 15° S., and the following section is exposed from the top downward:

Section in Chartley quarry.

	Feet.
Gray sandstone with small bands of pebbles and flattened stems of plants, affording traces of coal	20
Black, compact, argillaceous beds, slightly micaceous, containing worm burrows of a scolithoid habit; exposed	12

Scolithus beds.—The worm burrows referable to Scolithus at this locality are somewhat sinuous or often recurved burrows filled with material similar to the micaceous rock of the walls. The tubes vary from an inch to a quarter of an inch in diameter. Where the wall has broken away from the internal cast the surface is either smooth or rarely marked by minute cross striations. The tubes are closely set, sometimes apparently in contact. The depth of the burrow exceeds in most cases 2 inches, and is probably much deeper, but, on account of the interlacing of the tubes, this point can not easily be ascertained. There seems no sufficient reason for giving a specific name to these forms, since they have no importance in indicating horizons even within the limits of this small basin.

One and a half miles east by north of this locality are outcrops of compact argillite, succeeded on the south, near the head of Goose Brook, by gritty sandstones containing distinct pebble bands, the dip of the last being as steep as 80° S. These beds appear to be near the axial line of the

anticline which is traceable westward along the valley of Tenmile River in the Providence quadrangle.

Eastwardly there are no exposures along this strike line until we reach the small quarry of gray sandstones opened alongside the railroad between Britanniaville and the junction of the Attleboro branch railroad. About 1½ miles north-northeast outcrops occur on the west of Scudding Pond. About 4½ miles farther east coal has been reported on the southern border of Gushee Pond, but the stratigraphy of this region is concealed by drift.

South of this belt, in the latitude of Taunton, the Seekonk beds, overlying the above, come in with southerly dips and disappear on the west beneath the synclinal axis on which stands Great Meadow Hill. The strata are medium conglomerates, sandstones, and shales. Coal has been found in the uppermost beds underlying the coarse Dighton conglomerates about 1½ miles northeast of Great Meadow Hill. So far as has been determined, this is the highest occurrence of coal in the basin.

Taunton waterworks section.—Eastwardly and at a somewhat lower level, though probably in the horizon of the Seekonk beds, coal was again met with in sinking an artesian well for the waterworks of the city of Taunton. The well penetrated to a depth of 975 feet. The dip is reported to have been about 40° N. The following table gives the thickness of the several strata penetrated. The data were furnished by Mr. George F. Chace[1]. The measurements are approximate, and are based upon the nature of the materials brought up by the sand pump. The amounts indicate the *depth* of each bed.

Record of artesian-well boring at Taunton.

	Feet.
Superficial deposits (glacial drift)	85
Sandstone	95
Coaly shales	20
Slate, blue	85
Sandstone	20
Conglomerate, quartzose	12
Sandstone	30
Slate, blue	81
Sandstone	22
Slate, blue	80

[1] Fourteenth Annual Report of the Water Commissioners of the City of Taunton [for 1889]. Taunton, 1890. Plate opposite p. 28.

Record of artesian-well boring at Taunton—Continued.

	Feet.
Sandstone and coaly slate	15
Conglomerate, quartzose	13
Coaly shales	97
Slate, coaly, and sandstone	15
Sandstone	5
Coaly slate	13
Sandstone	7
Slate, blue	90
Coaly slate	10
Slate, blue	5
Coaly slate	5
Slate, blue	10
Coaly slate	15
Slate, blue	33
Sandstone	47
Coaly shale	40
Sandstone	25
Depth of well	975

The dip of the strata being, as stated, about 40° N., the actual thick ness of the strata passed through would therefore amount to 639.6 feet.

Westville section.—A partial section of these rocks occurs on the west bank of Threemile River from Westville northward. .The greater portion of

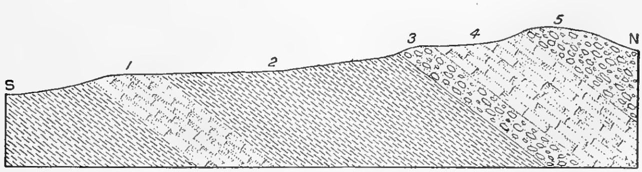


FIG. 28.—Geological section in Westville, Massachusetts, 1 mile west of Taunton. 5, coarse compound conglomerate, pebbles often a foot in diameter (Dighton group); 4, covered space, probably sandstones; 3, fine conglomerate, quartzose pebbles; 2, covered space, probably shales; 1, micaceous flaggy sandstones, much cleaved, and bearing casts and impressions of calamites.

the section is drift covered, but enough is exposed to show the character of these upper beds.

A similar section is repeated in most features 1 mile east of Taunton, along the road from Taunton to East Taunton.

Westward along the Providence and Taunton turnpike, 2 miles east of Great Meadow Hill, the sandstones and fine conglomerates underlying the

coarse conglomerates of the great syncline again appear in good exposures. Annawon Rock (if it is not a bowlder) and the conglomerates, certainly in place at this locality, come a little lower in this section.

Southward there are numerous outcrops of sandstone and conglomerate, until at Swansea Factory the northern edge of the Dighton conglomerate in the type syncline again comes in. The thick coating of drift makes a correlation with the corresponding outcrops on the two sides of the anticline which passes northeasterly across this field well-nigh impossible. Eastward in Dighton fine conglomerates come in below the coarse beds along Muddy Cove Brook. Similar conglomerates crop out east of the Taunton River, and again south of the syncline in Somerset.

The area southward to the Taunton River is occupied by sandstones and shales, the latter appearing along the river shore.

Taunton River Valley.—As a marked exception to the easterly strikes of the beds in this field, an outcrop just east of Judson post-office, on the eastern margin of the Taunton quadrangle, exhibits a north-south strike. This outcrop marks the turn of the strata around the eastern end of the Taunton syncline. The ridge, it is also worthy of note, is parallel to the course of the Taunton River in this section.

The Taunton River exhibits a marked adjustment to the stratigraphy of this portion of the field, although it is heavily masked by glacial drift. The section of the river from Taunton eastward is along the strike of the soft beds and across the strike of the hard beds. It is for this reason that its east-west reaches are long, its north-south courses short. South of Taunton the same adjustment is less perfectly exhibited. These facts indicate a well-excavated preglacial channel.

MIDDLEBORO QUADRANGLE.

But few outcrops of the Carboniferous are exposed within the limits of the Middleboro quadrangle, and it has not been possible to do more than to indicate on the map the area occupied by the Carboniferous formation in general without reference to horizons. The information gleaned from bowlders, while it does not permit the delineation of the exact distribution of strata, shows that this portion of the field is traversed by beds of conglomerate, sandstone, and slate resembling those of the Coal Measures, and probably representing the lower portion of that series.

South of Middleboro, on the west bank of the Namasket River, are three low outcrops of gritty slate with thin layers of white quartz pebbles, the size of the pebbles being not over an inch in diameter. Beds of this character are probably not far above the base. It is interesting to note again in connection with these beds the outcrop of granitite which occurs immediately north in Namasket village.

At the southwestern border of Great Cedar Swamp, although there are no outcrops, the abundance of slabby sandstones in the fences indicates the probable eastward extension of the sandstones which occur near the middle of the Coal Measures in the western part of the basin.

The area of felsites in Plympton has already been described (see p. 116).

CHAPTER VI.

ORGANIC GEOLOGY.

In 1840, Dr. C. T. Jackson stated, as a result of his survey of the Coal Measures in Rhode Island, that, "from the fossil contents of the Carboniferous clay slate, we have reason to regard it as a fresh-water deposit, either from lakes or from the estuary of some ancient river, whose waters may have brought down from the lowlands on its banks an abundance of these specimens of the ancient flora."[1] No observations of more recent date have been published to overthrow Jackson's hypothesis of the nonmarine origin of the sediments now preserved in the basin. Knowledge regarding the fauna and flora has been gained slowly, and mainly through the work of a few students resident in the Rhode Island part of the field.

Besides insects, the Pawtucket shales, according to Prof. A. S. Packard,[2] have afforded "the impression of an annelid worm, several shells of Spirorbis, and what appears to be the track of a gastropod mollusk."

INSECT FAUNA.

Mr. Samuel H. Scudder has described and figured a small insect fauna collected by various persons in the shales about the head of Narragansett Bay. The following list is compiled from his paper, Insect Fauna of the Rhode Island Coal Field:[3]

Insect fauna about the head of Narragansett Bay.

Name.	Based upon—	Locality.
Arachnida (spiders):		
Anthracomartus woodruffi	Abdomen	Pawtucket, R. I.
Neuropteroidea:		
Rhaphidiopsis diversipenna (Not extant).	Fore and hind wings	Sockanosset mine, Cranston, R. I.
Orthopteroidea:		
Palæoblattariæ—		
Mylacridæ—		
Mylacris packardii	Wing	Bristol and Pawtucket, R. I.

[1] Report on the Geology and Agriculture of Rhode Island, pp. 37–38.
[2] Am. Jour. Sci., 3d series, Vol. XXXVII, 1889, p. 411.
[3] Bull. U. S. Geol. Survey No. 101, 1893, 27 pp., 2 pls.

Insect fauna about the head of Narragansett Bay—Continued.

Name.	Based upon—	Locality.
Orthopteroidea—Continued:		
Blattinariæ (cockroaches)—		
Etoblattina illustris	Fore wing	Pawtucket? R. I.
sp	Fore wing	Silver Spring, R. I.
clarkii	Fore wing	Pawtucket, R. I.
scholfieldi	Fore wing	E. Providence, R. I.
sp	Hind wing	Cranston, R. I.
gorhami	Fore wing	Pawtucket, R. I.
exilis	Fore wing	E. Providence, R. I. (Drift.)
reliqua	Fore wing	Pawtucket, R. I.
Gerablattina scapularis	Fore wing	Pawtucket, R. I.
fraterna	Fore wing	Silver Spring, R. I.
Protophasmida (leaf and stick insects):		
Paralogus æschnoides	Fore wing	Silver Spring, R. I.

STRATIGRAPHIC POSITION OF THE FAUNA.

The discoverers of this interesting insect fauna appear to have done little toward establishing the horizon or horizons in which it occurs, if it has any assignable limits. The specimen of Etoblattina from Fenner's ledge in Cranston, so Mr. Scudder quotes, was found "near the extreme western upturned edge of the Carboniferous in the plumbago mining district, and [is] therefore probably older than the others."[1]

The localities which have so far furnished these insect remains are traversed by strata relatively low down in the Coal Measures section. The outcrops in East Providence are in the horizon of the Tenmile River beds. The shales of the Cranston series lying to the west of these exposures are probably in part still lower in the section, extending downward nearly to the base of the Carboniferous. It would appear, therefore, that, so far as at present known, this fauna ranges from near the base of the Coal Measures to and into the Tenmile River beds. The higher strata, which have a nearly equal thickness, have not afforded fossils. The locality at Bristol is somewhat in doubt as to its place in the section.

ODONTOPTERIS FLORA.

The flora of the Rhode Island Coal Measures, according to the list of plants collected by the Rev. E. F. Clark and identified by the late Leo

[1] Op. cit., p. 16.

Lesquereux, is peculiarly rich in species of Odontopteris. As yet the upper portion of the Coal Measures, from near the base of the Dighton group upward in the northern field, has afforded little or no evidence. From the list of localities which appear to have been visited in collecting the fossils in Lesquereux's list it is possible to draw conclusions of some value regarding the flora so far as it is known.

The localities, so far as the Providence quadrangle is concerned, are practically limited to the exposures which occur in the lower half of the series of sandstones and shales of the Coal Measures, or to essentially the same range as the insect fauna. Lesquereux[1] concluded from these plants that the Rhode Island Coal Measures were equivalent to the beds of the upper Carboniferous in Pennsylvania. Until the flora of the uppermost members of the period in this basin is known nothing further can be said regarding their Permian affinities. (See also pp. 170, 181.)

List of plants identified by Leo Lesquereux.[2]

Species	Locality.
1. Pecopteris dentata Brgt	Pawtucket.
2. Sphenopteris (Hymenophyllites) furcata	Valley Falls.
3. Sphenophyllum oblongifolium	Pawtucket.
4. Dictyopteris scheuchzeri?	Pawtucket.
5. Odontopteris stiehlerian	Pawtucket.
6. reichiana	Pawtucket.
7. var. latifolia	Pawtucket.
8. neuropteroides	Pawtucket.
9. Neuropteris decipiens	Valley Falls.
10. Goniopteris (Pecopteris) unita	Valley Falls.
11. Pecopteris lepidorachis	Valley Falls.
12. Asterophyllites equisetiformis	Pawtucket.
13. Pecopteris miltoni	Pawtucket.
14. Schizopteris (Rhacophyllum) trichomanoides	Pawtucket.
15. Oligocarpia gutbieri	Pawtucket.
16. Sphenopteris lanceolata	Pawtucket.
17. Odontopteris bairdii	Pawtucket.
18. Pecopteris hemiteloides	Pawtucket.
19. miltoni (same as 13)	Pawtucket.
20. abbreviata	Pawtucket.
21. arborescens	Pawtucket.
22. Pseudopecopteris dimorpha	Bristol.
23. Odontopteris cornuta	Pawtucket.
24. Parallel narrow rachises of pinnæ of No. 7, mostly deprived of leaves	Pawtucket.
25. Neuropteris dentata	Pawtucket.
26. Odonopteris obtusiloba?	?

[1] Am. Jour. Sci., 3d series, Vol. XXXVII, 1889, p. 411.
[2] Ibid., p. 229.

A more complete list of plants found in the Rhode Island Coal Measures has been compiled by the Franklin Society of Providence, and published in its Report on the Geology of Rhode Island, 1887.

COAL BEDS.

The following account of the coal beds in the basin, written by Edward Hitchcock, who descended into all the accessible mines, sets forth the condition of things as late as 1853, since which time few mines have been opened:

1. *Beds of coal in Mansfield.*—These have been opened in two parts of the town. One is near the center, where a shaft was sunk by the Mansfield Coal Company, some fifteen years ago, 64 feet, but only a little coal was found.

About the same time the Mansfield Mining Company sunk a shaft 84 feet near the Hardon farm, 2 miles southwest of the center. A drift was then carried across the strata, and it is said that seven beds, of various thickness up to 10 feet, were found. Dip of these beds, 53° NW. Strike, SW. and NE.

More recently, in 1848, I believe, the Mansfield Coal and Mining Company, through the enterprise and perseverance of B. F. Sawyer, esq., sunk a shaft near the same place, 170 feet and 10 feet in diameter, from which, according to the statements of Thomas S. Ridgway, esq., the engineer, they have carried a south tunnel 660 feet, and other tunnels and gangways to about the same amount. Not less than thirteen beds of coal have been crossed, but none of them thick. They are very irregular, sometimes swelling out to 6 or 8 feet in thickness, and then pinched up to a few inches. The dip varies from 30° to 70° NW., and the strike is nearly NE. and SW. Although these excavations are not far from the old Hardon mine, the beds are said to have little correspondence.

2. *Bed in Foxborough.*—This is only about 2 miles from the Mansfield beds, and two excavations were made there several years ago, and good coal obtained, but the pits were filled up so that I could not ascertain the strike, dip, and width of the bed.

3. *Beds in Wrentham.*—In the south part of the town a pit was sunk many years ago, about 170 feet, mostly in dark carbonaceous slate, and several beds found. The coal which I have seen from this spot is not good, having 40 per cent of ash. Strike of the bed, nearly E. and W.; dip, 45° N.

4. *In Raynham.*—An outcrop of coal appears in this town, about 3 feet thick, which has not been explored, except a few feet. Strike, N. 50° E.; dip, 45° SE.

5. *In Bridgewater.*—Indications of coal were shown me from the rock thrown up in digging a well in the south part of the town, but nothing further could be learned.

6. *In Taunton.*—Two miles northwest of the town, a similar opening was shown me, but I could not learn the dip and direction of the slate. Four miles to the west of the town, I was told, similar indications exist. The same is true of West Bridgewater, and in Berkeley coal plants are found, such as usually accompany beds of coal.

7. In Cumberland, Rhode Island.—This is called the Roger Williams mine, which was opened many years ago; but the works were burnt, and the explorations abandoned, but they have been resumed within a few years under the superintendence of Capt. Thomas Martin. A shaft has been sunk 300 feet perpendicularly, into which I descended with Captain Martin. The old bed, whose strike was nearly NE. and SW., has been abandoned, and by carrying a horizontal shaft 260 feet a new bed was struck, which, at the place, runs nearly N. and S. and dips west about 45°. The average width was stated to be 15 feet, and in some places 23 feet. If this be not a mere protuberant mass, occasioned by lateral pressure, it indicates a larger amount of coal than I have seen in any other mines in this coal field.

8. The Valley Falls mine.—This is scarcely more than a mile south from the Roger Williams mine, yet the strike of the beds will not allow us to suppose them connected. The operations here are carried on by the Blackstone Coal Company. A shaft is carried down, which follows a bed of coal, with a dip near the surface of 30° to 45°. This bed, which I examined several years ago, to a depth of about 50 feet, exposed a thickness of coal from 6 to 9 feet, and the direction was N. 50° to 60° E. Since that time the "incline," as the miners call it, has been pushed downward 500 feet, or about 375 feet of perpendicular depth, and, as already mentioned, the strata have been found to curve very much, and not less than five beds of coal have been crossed, the best having a width of 6 feet. One nest of coal was found 30 feet square.

9. In Seekonk.—I am informed by J. N. Bolles, esq., of Providence, that the outcrop of a bed of coal was found in digging a well in this place, only 15 feet from the surface. Its quality was similar to that found at Valley Falls. In the same region occur very fine specimens of coal plants, especially calamites.

10. In Providence.—The same gentleman, in boring for water in the north part of Providence, at the depth of 60 feet, struck a bed of coal dipping NE. 45°, which is 10 feet thick, and of the same general character as that at Valley Falls, which is known to burn well.

11. In Cranston, Rhode Island.—This town is on the west side of Narragansett Bay, along which the coal rocks extend as far as Wickford. In Cranston, according to Dr. C. T. Jackson, "slate, graphite, and impure anthracite" are found in an excavation 7 or 8 feet deep. Coal plants are very abundant on Warwick Neck, but no coal has been found.

12. In Bristol, Rhode Island.—The coal bed in this place is in the west part of the town, and the spot where it crops out is only a few feet above the harbor. It was discovered in sinking a large well. Although I descended into it, I could not ascertain the thickness of the bed, nor with accuracy its strike and dip. Approximately it runs N. a few degrees E., and dips westerly about 48°. The coal did not appear to me to be as much crushed as in some mines, and seems of an excellent quality.

13. Portsmouth mine, or Case's mine, in Rhode Island.—This mine, situated in the northeast part of the island of Rhode Island, was opened in 1808, which was earlier than the Pennsylvania mines were explored. At that time the mode of burning anthracite was not known, and the coal was not sought after, and the work was

abandoned in 1813 or 1814. Some years afterwards it was resumed, and in 1827, according to Mr. Clowes, the agent, 20 men and 5 boys raised about 4,400 tons of coal, coarse and fine. But the work was again abandoned not long after, and not resumed till 1847, when the mine was opened by the Portsmouth Coal Company, which has also ceased operations there. Mr. Barbour speaks of the amount of coal and rock, "principally the former," that has been excavated at this place, as about 100,000 tons.

Three beds were discovered at this place, "all of workable width." Dr. C. T. Jackson says that the bed last wrought was 13 feet thick. He states its strike to be S. 80° W. and N. 80° E.; dip, 35° southeasterly. Mr. Clowes, however, says that the beds run NE. and SW. and dip from 40° to 90° southeast. As the mine is now unwrought, I could not settle these points.

14. *The Aquidneck mine.*—[In the account of this mine it is stated that three beds of coal occur, only one of which, from 2 to 20 feet thick, was worked by the Aquidneck Coal Company. The middle bed was followed down to the depth of 620 feet, from which six gangways were extended, from 80 to 844 feet each. During the last half of 1851, 3,100 tons of coal were taken out, and an opening made into a subjacent bed.—J. B. W.]

15. *In Newport, Rhode Island.*—[An outcrop of coal in the southeast part of the town is described, and it is stated that during the Revolutionary war the British made excavations at this spot in search of fuel. The prospect is poor. The shale abounds in coal plants.—Abstract by J. B. W.][1]

Other references to coal will be found on pages 169, 182, 189, 190, 198.

SEARCH FOR COAL.

As the coal beds in this basin are mainly concealed in depressions filled with drift, or have their outcrop under river beds and swamps, the details of this report are mainly useful when made the basis of a process of exclusion, in which the prospector searches along lines of strike between bands of strata which are shown to be barren. So far as can be ascertained from field evidence, coal beds are likely to be found in the greater part of the field outside of the red rocks and lenticular areas occupied by the upper conglomerates, which together do not occupy an area greater than 30 square miles. In most of the area thus left, the dip of the beds is low, so that experimental borings are likely to penetrate several strata. Where the strata stand at a high angle the chance of meeting with coal beds is less good, although they may exist at one side of the trial boring in the same field. Such a belt of highly inclined strata runs north-northeast

[1] Mass. House Documents No. 39, March, 1853, pp. 9–13.

across the northwestern part of the Taunton quadrangle, through Norton, in the vicinity of Providence, and along the lower course of the Warren

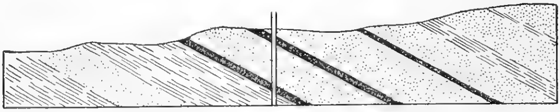


FIG. 29.—Case where a boring is the most economical and certain method of determining the presence of a series of coal beds in a given thickness of coal measures.

River in Swansea. In areas of vertical strata, trenching across the upturned edges of the beds would better serve the purpose. (See figs. 29 and 30.)

THICKNESS OF THE CARBONIFEROUS.

There are but few cross sections of the strata obtainable in the Narragansett Basin which are so far free from the perplexing hindrances set forth in the introduction to this report that the geologist can with confidence

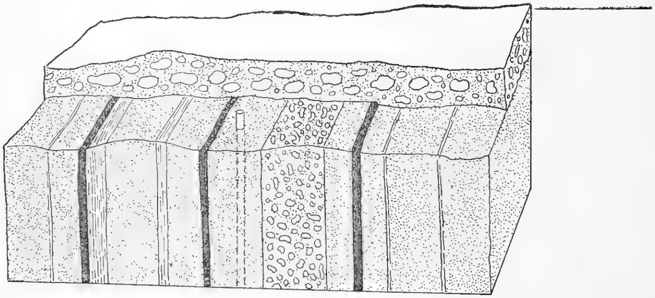


FIG. 30.—Case where a boring may miss an important coal bed and is not likely to discover more than one, and where a trench at right angles to the strike would reveal the true number of seams of coal.

give an estimate of the thickness of the beds entering into them. The most satisfactory line of section in the northern part of the basin passes from the southern margin through the Dighton-Swansea and Great Meadow Hill or Taunton synclines toward Mansfield and the northern border. The general relations of the structure along this line are shown in fig. 8 (p. 122). Measurements along this line give about 12,000 feet as the thickness of the

strata between the granitic base and the top of the Dighton group. The evidence on which this estimate is based is as follows:

From the south bank of the Taunton River north of Steep Brook to the axis of the Dighton-Swansea syncline there is a section from the base to the uppermost beds of the series. The distance along this line perpendicular to the strike is approximately 3 miles, and the dip of the beds is generally steep; it may be assumed to be as high as 45°. This gives 11,198 feet as the thickness of the strata remaining along this margin of the basin.

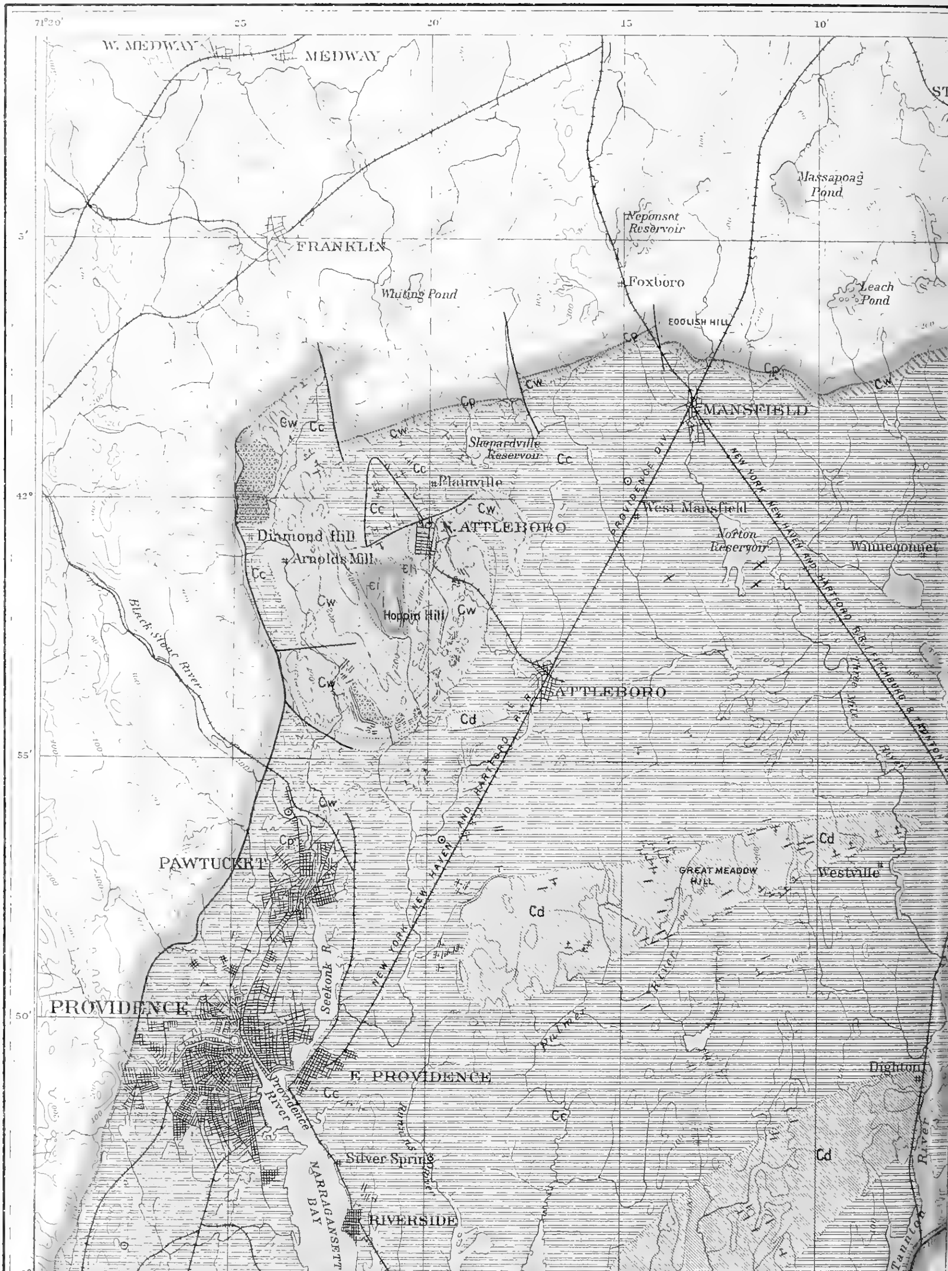
Between the axes of the Dighton-Swansea and the Taunton synclines is a distance of 6 miles. The intervening beds, in anticlinal position, though very imperfectly exposed, nowhere exhibit in the few exposures available for interpretation foldings or thrusts likely to diminish or increase the estimate of thickness based on measurements across the interval between the two synclinal axes. The dips on the southern side of the anticlinal axes are very steep, mainly above 45°; the dips on the northern side are much less steep, mainly below 45°. The lowest beds exposed anywhere along the anticlinal axis lie above the basal beds of the Carboniferous; so that estimates along this line must necessarily fall short of the base. Assuming 45° as the average dip over this anticlinal section, and since the beds over half the distance between the adjacent synclines have 3 miles of outcrop as before, we obtain the same amount as on the southern side of the Dighton-Swansea syncline. Inasmuch as this estimate of about 11,200 feet is a minimum and does not reach the base, it is probable that the beds increase in thickness toward the middle and now deeper part of the basin.

Northward from the Taunton syncline to the northern border near Mansfield there is certainly one anticlinal area, and another syncline in the Mansfield coal basin; but there are no exposures of the upper conglomerate series along this line, and the outcrops are totally inadequate for making even minimum estimates of thickness.

West of the line of section above described an approximate estimate of thickness can be founded upon the strata exposed between the western end of the Taunton syncline in Seekonk and the axis of the Attleboro syncline. From the Perrin's anticline, where there is a probable overthrust of the beds on the south, to the axis of the adjacent Attleboro syncline there is a fairly continuous exposure of outcrops, ranging in inclination from 45°, for a few hundred feet on the south, to nearly vertical for most of the

remaining distance to the Attleboro synclinal axis. Assuming 75° as the average dip across these upturned beds, which have a breadth of outcrop of about 11,900 feet, we obtain about 11,500 as a measurement of the thickness. Again this is a minimum estimate, reaching only from the top of the highest remaining beds in the synclinal trough to the lowest exposures in a broken anticlinal arch.

These measurements, taken in the northern part of the basin, across comparatively simple great folds, enforce the conviction that the strata now remaining in the deeper, central portion of this basin can not be less than 12,000 feet in thickness. This estimate agrees closely with that given for the Carboniferous strata of the Joggins section in Nova Scotia, which are about 13,000 feet thick.

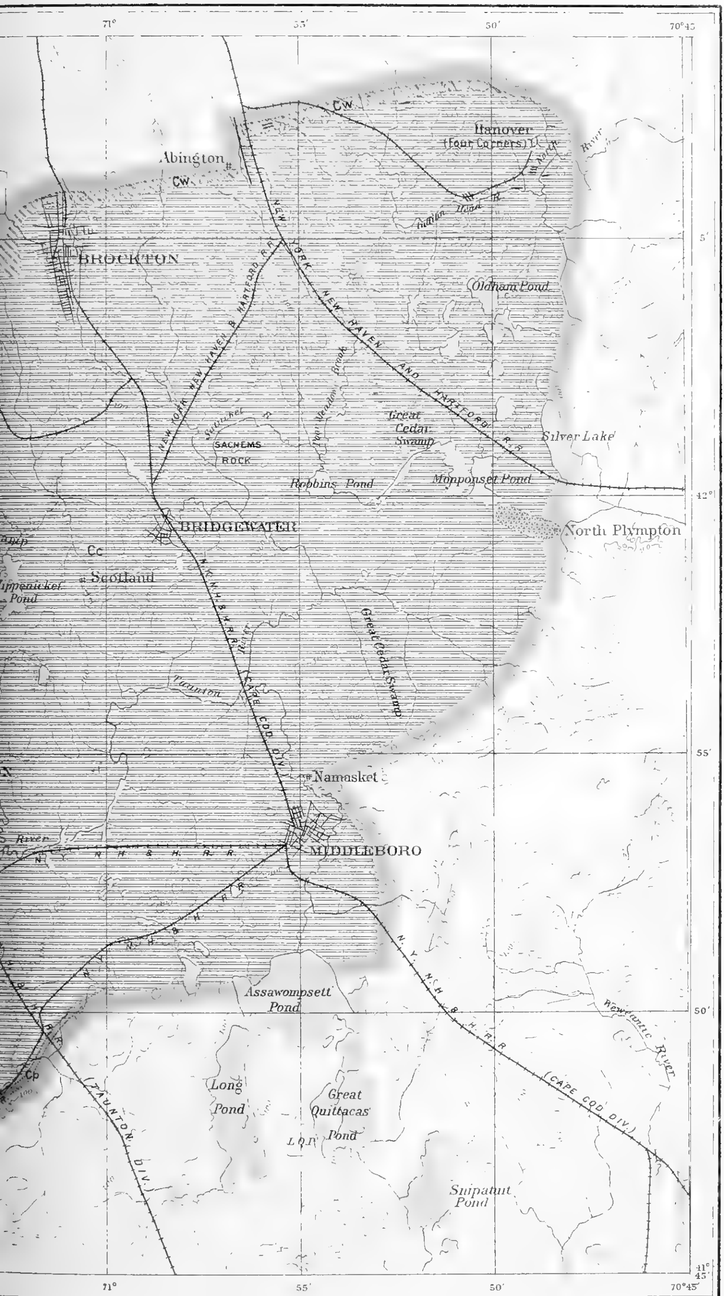


GEOLOGICAL MAP OF THE NORTHERN AND EASTE

BY J.B.WOODWORTH, ASSISTANT GEOLOGIST.

Scale

1 0 1 2 3 4 5



LEGEND

SEDIMENTARY ROCKS

CARBONIFEROUS

- Cd — Dighton group
- Cc — Coal measures
- Cw — Wamsutta group of red beds
- Cp — Pondville arkoses and quartz conglomerates

CAMBRIAN

- €l — Lower Cambrian

IGNEOUS ROCKS

- Diabase dikes
- Quartz-porphyry and felsites
- Diamond Hill quartz veins
- Pre-Carboniferous rock mainly granitite
- Coal shafts and bore-holes
- Faults

OUTCROPS

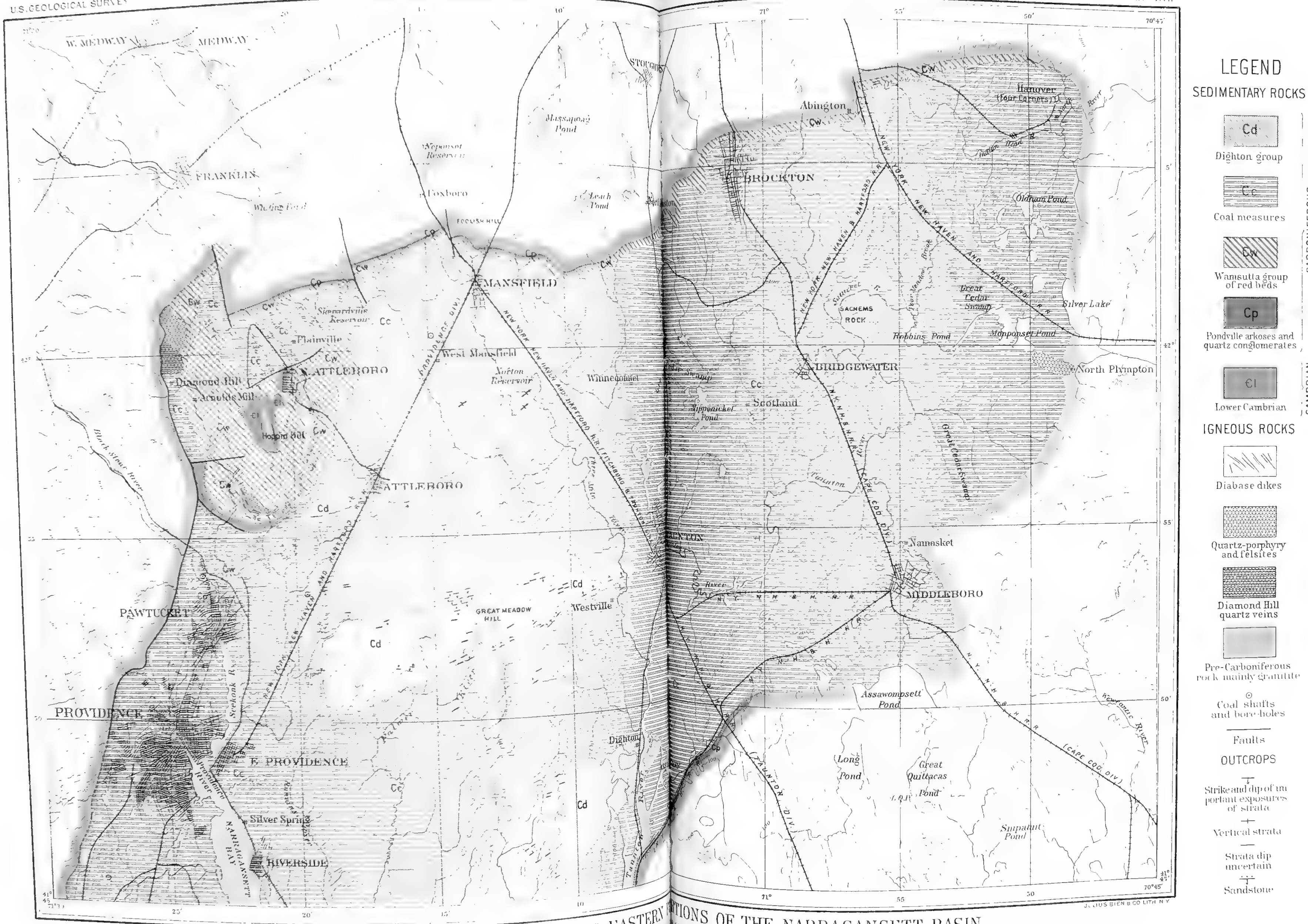
- Strike and dip of important exposures of strata
- Vertical strata
- Strata dip uncertain
- Sandstone

JULIUS BIEN & CO. LITH. N.Y.

...S OF THE NARRAGANSETT BASIN

...GIST IN CHARGE.

10 MILES



GEOLOGICAL MAP OF THE NORTHERN AND EASTERN [PORT]IONS OF THE NARRAGANSETT BASIN

BY J.B. WOODWORTH, ASSISTANT GEOLOGIST N.S. S... GEOLOGIST IN CHARGE.

Scale

10 MILES

ACKNOWLEDGMENTS.

I wish to express my indebtedness to my associates in this work for much guidance and aid, both in the field and in the laboratory, and particularly to Dr. Foerste for many suggestions and actual aid in delimiting the Cambrian, Carboniferous, and igneous rocks about North Attleboro. The following-named gentlemen rendered assistance at one time or another during the course of the field work: C. W. Coman, U. S. G. S.; Robert Wainwright, W. E. Parsons, Harry Landes, U. S. G. S.; J. Ralph Finlay, U. S. G. S., and G. W. Tower. To Prof. J. E. Wolff my thanks are due for examining many thin sections of rocks. To Prof. George H. Barton I am indebted for the privilege of reading a manuscript report, with sections, based upon his study of the Norfolk County Basin, and to Prof. A. S. Packard, of Brown University, for the use of the collection of plants from Rhode Island. All the photographs illustrating this monograph were taken under my immediate supervision by Mr. Philip P. Sharples, of Cambridge, Massachusetts.

APPENDIX.

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GEOLOGY OF THE NARRAGANSETT BASIN

Part III.—THE CARBONIFEROUS STRATA OF THE SOUTHWESTERN PORTION OF THE BASIN

WITH

AN ACCOUNT OF THE CAMBRIAN DEPOSITS

By AUG. F. FOERSTE

CONTENTS.

ILLUSTRATIONS.

GEOLOGY OF THE NARRAGANSETT BASIN.

PART III.—THE SOUTHWESTERN PORTION OF THE BASIN.

By Aug. F. Foerste.

CHAPTER I.

INTRODUCTION.

DIFFICULTIES OF THE FIELD.

The writer first studied the geology of the Narragansett Basin in the summer of 1887. Thereafter he spent a part of each summer in this field until 1890. His investigations during this time were confined almost entirely to the region around North Attleboro, and some attention was given to tracing the present margin of the Carboniferous basin. In the course of the latter work about three months were spent on the southern half of the Carboniferous basin. Some of these studies were recorded in a thesis, "On the Igneous and Metamorphic Rocks of the Narragansett Basin," 1890, deposited in the library of Harvard College. In the early summer of 1890 a short stay at Newport convinced the writer that an order of succession of the Carboniferous rocks could be made out, having the following character: (1) At the base a series of shales, now known as the Aquidneck shales; (2) above these, sandstone beds with some small pebbled conglomerates, now known as the Sakonnet beds; (3) a very coarse pebbled conglomerate, then already known as the Purgatory conglomerate. He then went to Swansea, around the margin of the great Dighton conglomerates, in order to see whether a similar succession could be made out

there. While in the midst of this work he was called away from this field to another division of the Survey. Only about four months had therefore been spent by the writer in this southern portion of the basin previous to the present summer (1895), when two additional months were occupied in field work. This report is the outcome of the observations made at these various times. No one can understand better than the writer both the shortcomings of the report and the difficulties of the field. While exposures are numerous in various parts of the basin, chiefly along the shores of the mainland and the numerous islands, they are so widely separated by the arms of the bay and by broad areas of sandy soil that an interpretation of the structural relations existing between the exposed rocks is exceedingly difficult, if not impossible. Under the circumstances, however, it is hoped that the report will at least add something to our knowledge of the basin and furnish a basis for future labors and rectifications.

As the result of much thought and care in the study of the exposures actually found, although within a limited time, the writer will express the following opinions: Isolated exposures of small extent, unless within an area of frequent exposures, are apt to be more misleading than serviceable in the identification of horizons, owing to locally sudden lithological changes, especially in areas occupied by the Kingstown series. Greatest weight in making out geological horizons and the order of succession should always be given to long lines of exposure. It is not considered advisable to attempt a division of the Carboniferous rocks into separate geological horizons until an acquaintance is made with the scattered Carboniferous exposures over a very large area—in fact, over at least half of the area investigated—since otherwise the importance of features of only local value is easily magnified.

It may seem trite to express such opinions, in view of the advanced state of methods of geological investigation, but these remarks are especially pertinent to the Narragansett Basin, where the investigator of a limited field, especially in the dubious country in southern Aquidneck, is liable to go astray on account of the absence of exposures at very critical points. Nowhere are isolated small exposures more liable to influence opinion as to the geological succession of neighboring larger rock masses than here, and nowhere is the possibility of consequent erroneous views greater, but the attempt has been made to overcome these difficulties, and it is hoped with at least a measure of success.

ARRANGEMENT OF REPORT.

A reference to the accompanying map (Pl. XXXI), illustrating the geology of the lower part of the Narragansett Basin, will show that more than half of the area investigated is covered by the waters of Narragansett Bay and its many ramifications. A large part of the remaining area, especially along the shore and on certain islands, is covered by sand and various glacial and more recent deposits. The rock exposures occur chiefly along the shore. Much of the geology is necessarily uncertain, and the writer claims only such an advance in the knowledge of the geological features of the region as a careful study of the meager data will admit. In preparing his report it seemed desirable to describe first the geographical distribution of the various rock exposures, their lithological characteristics, and their strike and dip, without any special reference to conclusions which might be drawn from these (Chapters II–VI). This seemed preferable, since the exposures furnish the basis for all conclusions, but the inferences drawn are not always as imperative as in the case of other geological fields where exposures are more frequent or admit of more ready interpretation. While, therefore, a description of the exposures would have permanent value, the interpretation of the geological structure might vary with the increase of our knowledge of the geological data involved. Many localities, at present still concealed by the soil, are likely to be exposed in the future by the construction of roads or the digging of wells, foundations, and sewers. The correlation of the beds exposed in various parts of the field, and the conclusions concerning their relative age, receive special attention in the later chapters of the report (Chapters VII–XI).

The description of localities in geographical order is begun in Chapter II with Dutch Island, the most western locality in the southern part of Narragansett Bay in which fossils have been found. In going from this island to Fox Hill and the northern part of Conanicut we remain in the same series of rocks, and are better prepared to understand the differences, stated later, between the Kingstown beds and the Aquidneck shales, which occupy most of the remainder of the island. After this, Hope and Prudence islands are described, these islands being more nearly in line of strike with Conanicut than with other regions southward, and presenting rocks at least of approximately similar horizons.

Chapter III is devoted to a discussion of the exposures on the western side of the bay. Directly west of Dutch Island lies Saunderstown. The shore exposures south of this locality show lithologically all the features of the Carboniferous of Dutch Island and northwestern Conanicut, so that, although fossils are not found, the geological position of the beds is fairly certain. Southward, however, metamorphism becomes more pronounced, the Carboniferous exposures are no longer so continuous, they are separated by large pegmatite intrusions, and finally appear only as rare inclusions in the pegmatitic granites of Boston Neck and Narragansett Pier. The gradual character of these changes prepares the student for the conclusion that even these southern rocks and the Tower Hill exposures are Carboniferous. From this region northward the Carboniferous age of the rocks must be conceded.

In Chapter IV the exposures between Providence River and Taunton River, on the northern side of the bay, are taken up.

Following the eastern shore of the bay southward, it is conveniently possible, first, to describe all that is accurately known of the Carboniferous formation on this shore, and then to discuss the probably pre-Carboniferous rocks of Little Compton. This is done in Chapter V.

In the same way, beginning with the basal arkoses at Sachuest Neck, it is possible to describe all the more evident structures of Aquidneck Island before the more doubtful regions near Miantonomy Hill, and then those toward Newport Neck. This is done in Chapter VI.

It has been the writer's aim so to arrange the materials as to proceed from the better known to the less evident facts and structures.

The conclusions founded on these observations form the basis of the second part of this report, including Chapters VII to XI, and have been placed toward the close. They are necessarily of a more argumentative character, and the attempt has been made to bring out more sharply the inferences deduced from the facts by removing from this part of the report all unnecessary references to the more minute details of the geological features presented by the individual exposures. It is this part of the report which must necessarily be subject to revision, and which nevertheless is the more important, since it gives the results of the work. No one has had more occasion to regret the scantiness of continuous exposures in an east-west direction in this area, across the strike, than the writer, for this has left his efforts in the field often of little avail.

CHAPTER II.

THE WESTERN ISLANDS OF THE BAY.

DUTCH ISLAND.

From the western side of the island, nearer its northern end, a triangular piece of sandy beach extends into the western passage of the bay. Southward from this beach there is a continuous exposure of Carboniferous rocks along the shore. The more northern portion consists chiefly of black shales, which sometimes are very coaly. At a point about 400 feet south of the beach and directly west of the largest building on this shore, a number of fern leaves were found in the coaly shale, the shale being free from any marked signs of metamorphism, excepting the usual cleavage. The strike of the shales is N. 30° E.; dip eastward, variable, but very distinct, averaging perhaps 45°. Sandy layers are more or less frequently intercalated in the shales. Farther south there is an alternation of sandstone and conglomerates with some coaly shales. The strike is N. 30° E.; the dip is still eastward. Along the last 1,000 feet sandstone prevails. Here is shown a fine instance of crumpled strata. The layers can be well distinguished, and the flexures which they have undergone can readily be traced. Notwithstanding the flexuring, the dip of the sandstone can be seen to be distinctly eastward. The strike is nearly north and south, or slightly east of north. Near the light-house there is not sufficient exposure to make a determination of the dip. Along the east shore northward from the light-house the crumpling of the sandstone continues. A fine exposure of conglomerate, forming a bed about 8 feet thick and free from crumpling, shows the dip to be about 50° E. The strike is N. 20° E. The conglomerate borders the western side of an embayment about a third of the length of the island north of the light-house. The point forming the eastern side of the embayment consists again of crumpled sandstone, with a few thin layers of conglomerate, the dip being distinctly eastward as far north as the wharf, a third of the length of the island from its northern

end. The same sandstones with thin conglomerate layers are also found north of the wharf, as far as the obtuse northeast angle of the shore. The strike here is N. 16° E., and the dip of the strata, as actually exposed, is nearly vertical, though a consideration of the more southern exposures of this series warrants the belief that the general dip is eastward.

In general, the strata of Dutch Island may be described as consisting chiefly of sandstones with subsidiary conglomerate layers, underlain on the extreme western border by a series in which black, often coaly, shales predominate. The general strike is N. 20° E., becoming more directly northward at the south end. The dip is eastward. A continuation of the strike northward would carry this series to the western side of Conanicut, at the southern end of the line of exposures corresponding to Slocums Ledge. Here, in fact, a similar series of rocks occurs, but the strike is more northward (N. 3° E.); the dip eastward. Continuing the strike southward, the most eastern exposure on Dutch Island should pass to the west of Beaver Head or Fox Hill, the nearest part of Conanicut. Yet, even if this be the case, there is no doubt that the Fox Hill strata belong to the same general series, and if they represent a higher horizon there is plenty of room on Conanicut for the combined series.

The degree of metamorphism shown by the Dutch Island rocks will be discussed in connection with the metamorphism shown by the corresponding rocks on Conanicut.

CONANICUT ISLAND.

FOX HILL, BEAVER HEAD.

Sandstone and several conglomerate layers are found along the more western margin of the hill along the shore as far as its southwestern point, the beginning of the beach. Some of the pebbles of the conglomerate layers are fairly large, and one or two a little over a foot in length were found. The beds containing these pebbles can not be compared, however, with the Purgatory conglomerates; still, the presence of large pebbles is noteworthy. Near the southern end of the series of exposures the coaly shales show considerable crumpling. This becomes less marked northward, where the strike is found to be N. 18° E., and the dip as low as 30° E. Over-

lying the sandstone and conglomerates along the entire northern margin of the hill is a series of black shales, at times very coaly. Intercalated with the shales were narrow bands of sandstone, indicating a low eastward dip, sometimes as low as 20°. This eastward dip is significant in connection with the question of the comparative geological age of the green shale lying immediately to the east.

NORTHERN HALF OF THE ISLAND, NORTH OF ROUND SWAMP.

The first exposure of rock on the western shore occurs just south of a very small sand beach, where the coast line of the island begins to take a direct northern course. Here occurs sandstone with some thin conglomerate layers showing a strike of N. 5° E. and an eastward dip. North of the beach there is a stretch of coaly shale, with an eastward dip. Then follows northward a series of sandstones with interbedded conglomerate layers, as far as a small stream entering the bay near the north end of Slocums Ledge. Northward coaly shale is again exposed, showing a strike of N. 8° E. and an eastward dip. Yet north of this is a long sandstone exposure with a strike of N. 13° E. and an eastward dip. Still farther north occur coaly shales again, as far as Fowler Rock, near the middle of Great Ledge. The line of shore exposures above mentioned, which might be called the *ledge exposures* on account of their proximity to Slocums and Great ledges, show the greatest degree of metamorphism among the rocks of the island. From Fowler Rock to a short distance northeast of Sand Point there are no shore exposures.

Northeast of Sand Point the shore lies on coaly shales interstratified with sandstones. The strike is N. 3° E.; the dip is also east. Northward there are sandstones with minor conglomerate layers, having the same strike. Farther north is more coaly shale, with intercalated sandstones, with the same strike of N. 3° E., and this is also shown by the most northern exposures on the western side of the island, coaly shales being exposed just west of North Point.

Exposures begin again about 1,200 feet east of North Point along the north shore and continue for several hundred feet. The rocks are chiefly shales, much squeezed in a direction from east to west, making a strike of N. 18° E. and an uncertain dip, which is believed, however, to be eastward. The next exposures along the eastern shore, going south, are almost directly

east of Sand Point, which lies on the western shore. Here are found gray sandstones and shales, with a strike of N. 8° E. and a vertical dip. In a small embayment to the south, almost east of the crest of the unnamed 100-foot hill indicated on the map, is black shale, often coaly. In one of the coaly shale layers in the most indented part of this embayment, fossil fern leaves are not uncommon. The strike is N. 13° E. and the dip vertical. South of this embayment occurs a line of sandstone, with a strike of N. 13° E. and a dip which is almost vertical, but slightly inclined toward the west; but there are very low dips in various directions farther south, indicating crumpling and folding in the rock. As the shore begins to curve toward the SSE. exposures are wanting, but farther south there is a grayish sandstone striking N.-S., with a dip of 70° to 80° E., toward the southwest of which is a dark shale, and farther southwest occurs a black coaly shale with a strike N. 9° E. For some distance southward there is an absence of exposures. Farther south, past the mouth of a little stream entering the bay, more of the coaly shale occurs, in the most western portion of this long embayment. A short distance south of a point directly west of the southern end of Gould Island black shales occur, with irregular dip and strike, indicating crumpling of strata. It is near the old ferry, and is the most southern of this series of rocks on the east shore.

A line connecting the small embayment immediately south of the old ferry with the pond east of Fox Hill would indicate approximately the eastern limit of the Kingstown sandstones with conglomerates and the coaly shales. South and east of this line lies the great Conanicut shale series, which is a part of the Aquidneck shale series, hereafter to be described.

The strike of both the eastern and the western portion of the exposures in northern Conanicut averages about N. 8° E. Along the western shore there is no marked crumpling, and the dip is distinctly east, averaging perhaps 40° to 50°. On the eastern side the dips are frequently vertical, and sometimes horizontal, as though considerable folding and crumpling would be shown if there were any long vertical sections across the strike

The western portion of the northern half of the island shows considerably more metamorphism than the eastern portion, and the most metamorphosed portion is that bordering the shore along Slocums and Great ledges.

Here the pebbles of the conglomerates have been squeezed into thin sheets, often several inches long and hardly more than a quarter of an inch in thickness, so that it is difficult at times to recognize the conglomeratic nature of a layer if seen in a section transverse to the cleavage, while along the plane of shearing the pebbles are very easily recognized. This flattening of the pebbles is shown to an equal degree in the conglomerate at the western base of Fox Hill, on Dutch Island, and along the more northern and eastern exposures on Conanicut.

The sandstones and shales exposed along the shore at Slocums and Great ledges frequently contain garnets. These are of much larger size than any found farther north on the island. Garnets in the sandstones on the eastern side of Conanicut are very small, and those in the shales are yet smaller.[1]

A walk around the border of the island is very instructive. The most eastern coaly shale exposures are, except for their cleavage, but little affected by metamorphism, and for this reason it was not difficult to find fossil ferns there, while along the ledge exposures on the west the frequency of large garnets, and often also of staurolites, makes the detection of fossil ferns in these shales very difficult. Nevertheless, Prof. T. Nelson Dale found a number of well-preserved fossil ferns somewhere along the ledge exposures, in a layer of black coaly shale, hardly more than a foot thick, included between shales containing staurolite, garnets, and ottrelite.

Staurolite was found only along the cliff exposures, but in places it was very abundant. It was not seen on Dutch Island or Fox Hill. Garnets were found in the shales on Dutch Island, but in some of the shales they were entirely absent. In the black and coaly shales at Fox Hill they were rare, although occurring in great numbers in the overlying green schists south of Fox Hill. At several localities on Conanicut and Dutch islands radiate aggregates of a greenish mineral are found rather abundantly in this series of rocks. These aggregates are instructive in connection with the exposures on Gould Island, in the northern part of Sakonnet River. While the metamorphism undoubtedly increased in intensity westward, in this region it did not increase regularly so as to make Fox Hill and Dutch Island show more metamorphism than the cliff exposures of Conanicut.

[1] On metamorphism in the Rhode Island coal basin, by T. Nelson Dale: Proc. Newport Nat. Hist. Soc., Doc. 3, 1885, pp. 85–86.

SOUTHERN HALF OF THE ISLAND, SOUTH OF ROUND SWAMP.

SHALE REGION.

The most northern outcrop of the Conanicut shales is in a small embayment north of Potters Cove, about 1,800 feet south of the old ferry. They are here very thin and fissile. They are again exposed for quite a long distance along the northern part of Potters Cove. At its southern extremity, and thence all around the margin of Freebodys Hill and beyond Jamestown Ferry, there is an almost continuous exposure, the outcrops ceasing about half a mile south of the ferry point. At Taylors Point the shale contains quartzitic layers. If these are original interstratified sandstone layers there has been much lateral crumpling. Nevertheless, the beds show a generally low dip. Along the eastern shore of Freebodys Hill there is distinct color banding, accompanied by considerable crumpling. The most northern of the outcrops of the shales along the western shore lies within half a mile north of the western Jamestown ferry. Thence outcrops occur at more or less frequent intervals as far as the marshy land, a short distance south of the western ferry; then, after a short interval, along the eastern shore of Mackerel Cove. Shales occur again a third of a mile south of the western ferry, along the southern margin of Dutch Island Harbor, on the northern edge of the southern half of Conanicut, east of the pond near Fox Hill. South of Fox Hill they occur again at the end of a beach about a sixth of a mile long. Here they are very glistening and are filled with some ferruginous mineral, not closely examined in the field, but probably pyrite. Thence the same shales are found around the entire margin of this part of the island, around Beaver Tail Head, thence northward into Mackerel Cove to its northern extremity, and thence from the eastern end of the sand bar connecting the two parts of the island, down the eastern side of the cove, to a point where a small stream enters the cove.

Two minette dikes cut the Conanicut shales in the southern half of the island. One dike extends from the northern side of Hulls Cove to the northern edge of Austins Hollow; the other extends from Lions Head to the Southern edge of Austins Hollow.

The color of the Conanicut shales is somewhat variable. Where dry and long exposed to the action of weathering they are lighter in color, verging toward greenish, with a tint of blue or brown; where wet they

are darker in color, usually dark blue, often almost black, but not of the dense black hue characteristic of the shales often called coaly in this paper, in which fossil ferns are usually present. These shades of color are also found where they are not due to variations of moisture, but in general the dark-blue type prevails, excepting in the more weathered portions. Dark color banding not infrequently indicates the true dip and strike. While the general strike is undoubtedly northerly, the dip is not so easy to determine.

While the writer believes that the series of shales as a whole overlies the series of sandstones, conglomerates, and coaly shales already described, and while an easterly dip would best accord with such belief, it is only proper to mention that the time at his disposal did not enable him to make a satisfactory study of the problem. The dips on the western side of the shale series were often found to be very steep, almost vertical, and in some very large exposures more or less steep westward, while on the eastern side, as far as the northern part of Mackerel Cove, the dips were less vertical and were often eastward. The chief reason for believing that the Conanicut shales are above the Kingstown sandstone conglomerate and coaly shale series is their occurrence east of the latter, especially east of Fox Hill, and the uniform eastward dips of the latter series, especially at Fox Hill, but also on Dutch Island. Unfortunately, the uniform east dip along the western margin of northern Conanicut is not continued in an equally apparent manner in the more crumpled and folded series on the eastern side of the island.

GRANITE AREA, THE DUMPLINGS, AND ARKOSE REGION WEST OF THE DUMPLINGS.

Coarse granite, in part filled with large phenocrysts of orthoclase, occupies the southern end of the northeastern half of Conanicut, from the southern side of Bulls Point to Mackerel Cove. North of the granite, on the Mackerel Cove side, is a considerable exposure of arkose. Near the granite the arkose contains some of the large phenocrysts of orthoclase derived from the granite, scarcely broken up. Farther from the granite the large phenocrysts are more rare. Interbedded with the arkose are more carbonaceous, sandy, and shaly layers, with strike about N. 70° E. near the granite. The arkose is exposed along Mackerel Cove as far as a little stream entering the cove from the east. North of the mouth of this stream only the Conanicut shale series is exposed. The color banding of this shale

is at several points very distinct, and a careful examination of the same seems to indicate that the shales strike more nearly north-south, and dip at a low angle eastward. The stream indicates a line of fault between the shales and the arkose beds.

The relative age of the arkose beds and of the green Conanicut shales is not known. The arkose beds are undoubtedly Carboniferous. They give evidence of interbedded layers of somewhat carbonaceous shales. Some of these shale layers were thin, and suffered enough erosion from the variable currents present during the deposition of the grit to cause the remnants of the shale layers to appear like fragments of shale inclosed in certain courses of the grit. The green Conanicut shales are also Carboniferous. But there is no gradation of the grit into the Conanicut shale immediately to the north. Those parts of the arkose and of the Conanicut shales actually exposed along Mackerel Cove are therefore not strictly of the same age, although both are of Carboniferous age. A line of fault separates them. Since neither the upthrow nor the downthrow of the fault is known, it is impossible to determine by comparison of their exposure which is the older.

North of the eastern half of the granite area is found a greenish rock, here called the Dumpling rock. In places, especially in the northern outcrops along the shore, it is purplish, looks very much like an argillite, and seems to show genuine stratification. Farther south along the shore, at a promontory, it seems to contain pebbles. Still farther south, however, and along all the inland exposures, from the eastern side of Conanicut, along the northern margin of the granite area, toward the cove, the Dumpling rock is greenish in color, fine grained, of homogeneous texture, gives no evidence of clastic origin, is cracked in all directions, and does not have the appearance of a stratified rock. It bears a strong resemblance to the greenish rock found along the southern Newport Cliffs south of Sheep Point. To a less degree it resembles the greenish and purplish rock forming the middle third of Newport Neck. The most northern outcrop of this greenish rock is along the shore half a mile south of Jamestown Ferry. Thence it extends inland for half a mile in a southwest direction. Here the northern boundary seems to meet the southern in a sharp angle (see map, Pl. XXXI). The granite area lies but a short distance southward, and the northern border of the granite passes irregularly eastward, south of the Dumpling rock area, at first about N. 70° E., then S. 70° E. to the

shore a third of a mile northwest of Bulls Point, then reappearing on the promontory of Bulls Point, forming the northeast shore of the promontory to its extremity. The southern part of the rock island southeast of Bulls Point is granite. All the rock islands north and northeast of Bulls Point, including the Dumplings, are formed by the greenish Dumpling rock. This Dumpling rock is older than the granite. This is shown by the fine-grained structure of the granite wherever it comes in contact with the Dumpling rock. The greenish Dumpling rock along a road near the contact half a mile northwest of Bulls Point, and along the point itself, is penetrated by dikes of pink or reddish aplites of rather fine grain. This aplite is still more common in the granite area, and evidently represents a later intrusion, after the great granite mass had cooled considerably. Sometimes the aplite is rather coarse, but never so coarse as the granite mass itself. The Dumpling rock is considered an argillite, formed by the metaphoric action of pre-Carboniferous granite on still earlier, possibly Cambrian, shaly rock.

At no point does the greenish Dumpling rock of Conanicut come in contact with the Conanicut shale series at the surface. The nearest points of approach are at least several hundred yards distant. The arkose may once have extended along the northern part of the greenish Dumpling rock toward northern Rose Island and southern Coasters Harbor Island. There is certainly a great temptation to assume the existence of an island[1] in Carboniferous times, consisting of granite, Dumpling rock, and the Brenton Point shales. This island would include the Newport Harbor Islands south of the line above mentioned, the area east of southern Mackerel Cove on Conanicut, and Newport Neck. Kettlebottom Rock, a short distance south of the southwestern end of the granite area, consists of Conanicut shale.

HOPE ISLAND.

The pier is at a projection about 900 feet south of the northeast angle of the island. From the embayment on the eastern side of the island south of the pier to a similar indentation on the western shore an east-west fault seems to run. The beds both north and south of the pier seem to have very steep dips, with variable strike. At the northeastern angle of the island, however, they dip at a low angle northeastward. The rock at this end is a white quartzitic sandstone with few pebble layers. Westward

[1] T. Nelson Dale: Am. Jour. Sci., 3d series, Vol. XXVII, 1884, pp. 217–228, 282–289, map.

along the northern margin of the island black shales and fine-grained sandstones underlie the sandstone, dipping northeastward. Farther west, extending from the northwest angle of the island to the indentation northwest of the dwelling house, is more white quartzitic sandstone, dipping under the black shales at a low angle to the northeast. Near the southern end of this part of the shore a black shale layer is seen to underlie the sandstone.

South of the fault line, on the west shore, are found in succession the following rocks, numbered downward in the section:

(1) Black shaly rock, strike N. 30° E., dip 80° E., the strike continuing far southward.

(2) Conglomerate with small pebbles and with flakes of black shales in the lower courses.

(3) Black shale.

(4) A considerable thickness of sandstone, becoming conglomeratic southward along the strike; dip about vertical, becoming 60° W., then 45° W., then more nearly vertical, and finally, on going southward, 70° E. again.

(5) Black shales adjoin the sandstone on the west. This black shale layer makes its appearance in the projection southeast of Gooseberry Island and continues to be exposed or otherwise indicated for a distance of 1,000 feet. The strike is parallel to the shore, and the dip is 70° to 60° E.

(6) West of this black shale layer occurs sandstone, more black shale, and again sandstone on the shore southeast of Seal Rocks.

(7) East of this long black shale layer occurs a great mass of sandstone as far as the south end of the island, becoming conglomeratic along the eastern side of the island, being there often a rapid alternation of sandstone and conglomerate layers. Along the eastern side of Hope Island the dips are low eastward, usually 30° to 45°.

The sandstones of Hope Island are very white and quartzitic, but abundantly specked by some small black micaceous mineral, probably biotite. The blue and gray color of the standstones, so characteristic in less metamorphosed regions, has disappeared. Pebbles are present to a certain measure in all the sandstone layers, but on the western side of the island the sandstone predominates greatly, while along the eastern shore almost half of the rock is conglomeratic. The black shaly and evidently Carboniferous beds are found only along the western and northern shore, and evidently form

the lower beds of the small section here exposed. These shales are everywhere filled with dark minerals, which in some cases resemble, macroscopically, ottrelite, and in other cases may be some other dark micaceous mineral. The pebbles of the conglomerate are uniformly small, usually not over $1\frac{1}{2}$ inches in diameter. Many of them are distinctly quartzitic or granitic; in the latter case of medium grain, of bluish tint, and without phenocrysts.

There has been no flattening of pebbles or considerable shearing, metamorphism being, however, abundantly shown by the frequent presence of black mica in the sandstone and of ottrelite in the black shales.

A continuation of the strikes along the entire western margin of Conanicut would carry the series there exposed to Hope Island. The form of the sea bottom between these two islands also suggests a general continuity of strata, and the rocks exposed on Hope Island are believed to belong to the same general series as those exposed on Conanicut, although possibly just beneath that series, as is indicated by the more quartzitic phase and the general absence of the more argillaceous or slaty pebbles, the latter being more frequently quartzitic and granitic. At Hope Island, however, the strikes are much more toward the northeast, averaging N. 30° E.

A continuation of the strike would carry these rocks toward Johnsons and Pine Hill ledges south of Pine Hill Point, on the western shore of Prudence Island. Whether they occur there could not be determined.

PRUDENCE ISLAND.

The lowest rocks exposed on the west side of the island are found north of Prudence Park wharf, and continue thence northward, forming the shore for a little over a mile, with an average strike of N. 20° E. and a dip of 25° to 45°, at one place 60° E. The average dip is about 35°. At the wharf the sandstone is bluish, with a few thin conglomerate layers. The pebbles are elongated, but much less than at Hope Island, and the general metamorphism is evidently less. The sandstone series appears again about a quarter of a mile northward, at the end of a long inward curve of the shore, where it contains thin conglomerate layers. Thence it follows the shore northward, the shale series often appearing in contact with the sandstones on the eastern line of outcrop, on the top of the bank. Black carbonaceous streaks often band the sandstones. At some

points the cross bedding is well marked. Thin but elongated pockets of ottrelitic coaly shale are found in places not far northward. Within 2,700 feet of the wharf scattered pebbles, sometimes $3\frac{1}{2}$ inches long, not at all flattened, occur in the sandstone. In a few of these pebbles oboli were found. The oboli occur again northward in a thin layer of conglomerate, the pebbles of which are sometimes $1\frac{1}{2}$ inches long. The oboli are found once again, about 700 feet north of the first-mentioned locality, in pebbles scattered through the sandstone. The gray sandstone is not infrequently banded with more carbonaceous layers. Farther north long, thin fragments of carbonaceous shale occur in small conglomerate layers. A little more than three-quarters of a mile from the wharf the flattened leaf-like plant remains occur, such as are found at Hills Grove, Warwick, and Silver Springs, East Providence. The outcrops along the shore cease about a mile north of the wharf. Northeastward of this, in the field, a sandy outcrop, probably belonging in the next higher series, occurs. In general, the series here described is composed of sandstones. The absence of coaly shale layers in it does not signify much, since the vertical section here exposed probably does not exceed 50 feet.

The occurrence of a shaly series over that of sandstones all along the line of outcrop has already been noticed. This shale series is well exposed along the long inward curve of shore north of the wharf. The lower courses immediately over the sandstone look very much like the dark-blue shales of the Conanicut series, but frequently contain ottrelite and are banded with more frequent and much larger layers of a very fine grained sandstone, which has been less affected by shearing. Above these beds occur decidedly coaly shales, often siliceous from the presence of minute clastic quartz grains. Above these again occur the fissile dark-blue shales. The color banding of the shales is often very well shown, and since there has been no crumpling, or violent folding, it indicates the strike and dip very well. The strike averages N. 20° E., and the dip is about 35° E. The upper dark-blue fissile shales are exposed at a number of points halfway up the hillside east of the wharf. The very coaly black shales form the shore south of the wharf for a distance of over a mile. It must not be imagined from this that the coaly shales are perfectly distinct from the dark-blue members; on the contrary, they are interbedded with the dark-blue shales at various levels, but nowhere else in the series is so much coaly shale

found as at this level. The general strike is parallel to the shore, about N. 10° E. south of the wharf, and N. 3° to 5° E. farther south. The dip, which is 25° E. for the greater part of the shore exposure, becomes 40° E. near the southern end. Here there is also much local crumpling, which brings the color bands of the rocks often to a vertical position. The crumpling takes place in a direction N. 60° E.

South of the wharf the coaly shale often shows distinct color banding. Gray, rather coarse sandstone occurs along the top of the cliff. The shale is frequently ottrelitic. About 3,375 feet south of the wharf fossil ferns were found in the coaly shales, where finest grained and least ottrelitic. Ferns are difficult to find in this series. It is best to take each slab of shale in the hand and hold it so that the sunlight will bring out in sharper relief all the unevenness of the surface. When the fern-leaf impressions are once found, the character is readily enough recognized. In the sandstone which occurs in the coaly shale series at this point was found the impression of a very large calamite. The longitudinal ribs were very coarse and distinct, and although the specimen was about 14 inches long and 4½ broad, yet it showed not a single joint.

The most northern exposure on the east side of the island occurs about two-thirds of a mile north of the light-house at Sand Point. Here is found a rock belonging to the shale series, finely color-banded, very micaceous, but not fissile. The strike is N. 12° W. and the dip 75° W. The next exposure is hardly half a mile north of the light-house. It is very dark-blue ottrelitic rock, belonging to the shale series. Its strike is about N. 4° W. and its dip about 80° W. From the south side of the light-house southward for a distance of 1⅓ miles there is a continuous exposure of the shale series along the shore, after which there are several more isolated exposures for about a quarter of a mile farther. The rocks on this side also belong to the shale series, although evidently higher than the basal part of that series as exposed on the west shore, since neither the sandstone-conglomerate series below nor the lower black coaly shale layers are here exposed. These shales usually appear so different from the Conanicut shales that at first sight their close similarity might not be recognized, yet careful observation will show at once the same sericitic micaceous structure. The rock is usually rather firm, but frequently the shaly structure is more developed and then the rock resembles in every particular the greenish and

the dark-bluish shales of Conanicut. The color banding is usually very pronounced, and since the contortion and folding of strata is less, the general strike and dip of the rocks can be readily determined. These shaly rocks differ considerably from the Conanicut shales, however, in the more frequent presence of sandy courses, varying from 1 inch to 8, 12, and even 20 inches in thickness. These have usually been less affected by cleavage. There are also distinctly conglomeratic beds present, although these, except in the case of two beds, occur only in very thin layers. Darker, more coaly phases are present in the shales, more carbonaceous than any observed on Conanicut. The general color of the shales on the shore, where not moistened by water, is often, for rather long stretches, a peculiar silvery green, which resembles some phases of the greenish shales at Eastons Point. The darker shales are frequently ottrelitic. Notwithstanding all these differences, a person acquainted with the varying aspect of this series will readily satisfy himself as to its identity with the Conanicut shales.

The general strike for a distance south of the wharf is N. 10° E., dip 70° W. About five-sixths of a mile south of the light-house the shale is darker, more carbonaceous, and ottrelitic. Farther south thin conglomerate beds show stretched pebbles, usually not exceeding half an inch in length. Yet farther to the south more carbonaceous black shales occur close to the inward curve along the shore. Farther on there is conglomerate with pebbles an inch long, and a little over a mile south of the light-house a 3-foot layer of conglomerate is found with pebbles often $3\frac{1}{2}$ inches long. The pebbles are usually greenish, as though lithologically similar to the shales; they are rarely quartzitic. Still farther southward more ottrelitic dark shale is seen. Fine color banding is often shown. Cross bedding is common in the coarser sandstones. Thin conglomeratic layers begin to be more frequent. Near this point the continuous exposures cease. At the southern end of these exposures the strike is N. 20° E., the dip still 70° to 80° W.

At the next exposure southward there occurs a more carbonaceous form of the shale, black and ottrelitic. Strike N. 28° E., dip 60° to 70° W. The next exposure, more greenish, gives again strike N. 13° E., dip 88° W. Banded, slightly ottrelitic shales form the last exposure, $1\frac{2}{3}$ miles south of the light-house; strike N. 33° E., dip 80° W.

Potters Hotel is located two-fifths of a mile directly west of the lighthouse. Southeast of the hotel, in the fields, at several localities, some of them halfway down the hillside, occur fairly coarse sandy layers, sometimes slightly conglomeratic, accompanying the dark-blue shales. They represent higher horizons in the shale series, and form the highest land surface on the island. Their strike is about N. 10° E., the dip 80° W.

The strike on both sides of the island, in the section crossing near Potters Hotel, is approximately parallel to the shore. The rocks on the western side dip east, those on the eastern side dip more steeply west, and the general structure of the island is believed to be a syncline. The wash of the waves has cut a bench into the east-dipping shales south of the wharf on the western side of Conanicut (Pl. XXIII, p. 352). That the rocks on this island have been less metamorphosed than those in Hope Island has already been noticed.

CHAPTER III.

THE WESTERN SHORE OF THE BAY.

FROM SAUNDERSTOWN TO NARRAGANSETT PIER.

ALONG THE SHORE.

About a quarter of a mile south of Saunderstown occurs, along the shore, black shaly rock, originally a very fine-grained carbonaceous sandstone, and a light-colored coarser quartzitic rock, representing an original coarse-grained sandstone, with but little carbonaceous material. The shaly rock is full of a micaceous mineral, and also contains black specks, which in part are probably biotite and in part some other mineral. The coarse-grained sandstone has black mica abundantly disseminated throughout it, and not collected in patches as on Hope Island. The strike is N. 20° E., dip 40° E. Southward some of the coarse-grained sandstone contains white mica; yet farther south very small pebbles begin to appear in the sandstone, usually in thin layers, forming a small part of the total thickness of the sandstones. Black, shaly, very fine-grained rock continues to be interstratified with the sandstones. Strike N. 30° E., dip often as low as 25° E. The pebbles are usually less than 1 inch long, and have been drawn out and flattened by shearing. At first, black shaly rock and sandstone alternate rather frequently just north of a small stream entering the bay; sandstone very largely predominates. South of the brook there is again an alternation of sandstones and black shales, and the low dip of 30° E. becomes 40° E., then steeper, until it is soon practically vertical; after which the dip becomes westward, about 70° W. at first, and finally, at a point 1,250 feet north of the South Ferry wharf, it is 40° W. Here the section is cut off transversely to the strike by a large pegmatite dike. South of this dike the lowest rocks are black shales, almost horizontal, overlain by quartziferous sandstone with white mica, containing small pebbles, overlain by black shale dipping 20° E. The low eastward dip continues

CONTACT OF PEGMATITES WITH KINGSTOWN SHALES SOUTH OF WATSONS PIER, RHODE ISLAND. LOOKING NORTH.

almost as far as a very large pegmatite dike about 600 feet north of the South Ferry wharf, just north of which the dip becomes low west. South of this pegmatite dike the low eastward dip continues.

North of South Ferry wharf occurs a considerable thickness of sandstone of rather small grain and somewhat bluish color, with black shale higher in the bank. South of the wharf lighter-colored sandstone appears, with very small pebbles and darker, more shaly rock, strike N.-S., dip 70° E. Farther on there is no exposure for a little over half a mile, until the northern end of the Bonnet is reached.

At the north end of the Bonnet there is sandstone with strike N. 8° E., dip low east. A very large pegmatite dike occurs at the northeast angle of the Bonnet. South of this dike the strike is N. 8° E., dip 60° E. From here to the southern end of the Bonnet there is an alternation of sandstones and black carbonaceous shaly rocks. The thickest bed of the black shale has a thickness of at least 40 feet. The strike at the south end remains the same, N. 8° E., dip steep east, near the water's edge as low as 45°; steeper higher on the banks, as high as 60° or 70°. Whether this indicates a local flexure or a syncline toward the east can not be determined. Some of the sandstones are very quartzitic, with much white mica. West of Bonnet Point is a rapid alternation of sandstones and black shales as far as the beach. The frequency of coarse quartz grains in some of the sandstones is noticeable. Strike N. 8° E., dip 60° E.

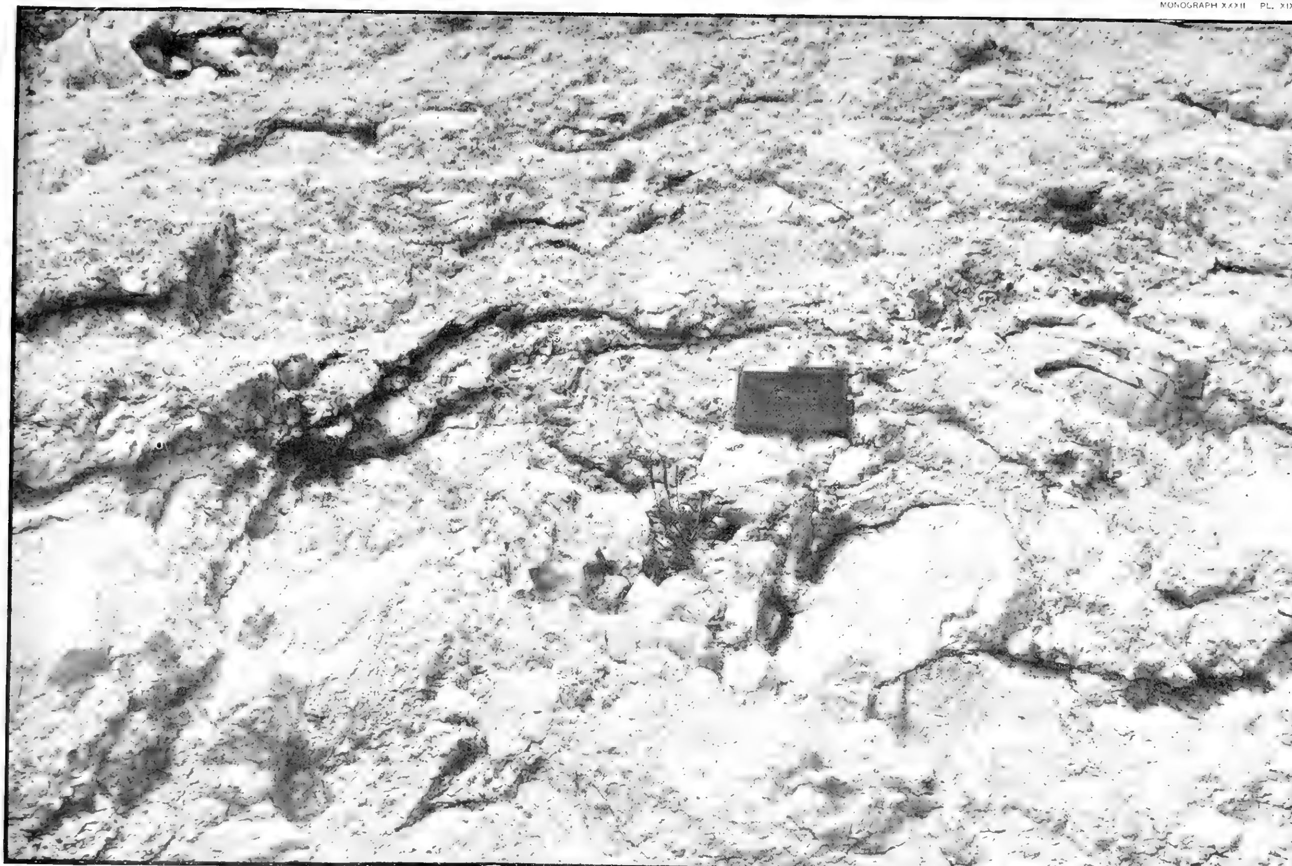
At the west end of the beach south of Wesquage Pond, the Carboniferous series is exposed again. The beds are here micaceous sandstones with darker layers. The strike is parallel to the shore, N.-S., dip 15° E. The Carboniferous series terminates about 200 feet south of the first exposure, in contact with a very thick, coarsely pegmatitic dike. This dike borders the shore southward for a long distance (Pls. XVIII, XIX, XXV), but about 1,200 feet north of Watsons Pier it includes small fragments of the Carboniferous sandstone, and almost surrounds a very large mass of the Carboniferous. The dip of this great block is still east. The large area toward the east of the large pegmatite dike which follows the shore is believed to be all underlain by Carboniferous rocks now worn away by the sea and covered by its waters.

Where the south trend of the shore changes to the southeastward, toward Watsons Pier, the strike brings these hidden Carboniferous rocks again into

view, with a strike fault contact over the pegmatite; strike N. 3° E., dip 45° E. These Carboniferous rocks are chiefly sandstone, very quartzitic, with white mica, and small specks formed by a black mineral. Some more carbonaceous, darker courses come in just north of the boathouse. Alternations of the sandstone and darker shaly rock continue as far as 120 feet beyond Watsons Pier; strike N. 7° W., dip 60° E. Lighter and darker colored sandstones continue to form the shore until it begins to turn southwestward, but an unusually large mass of pegmatite borders it on the east. West of the angle just mentioned, which is a southward-projecting point of pegmatite, the Carboniferous sandstones are seen again, with the same strike, but with a nearly vertical dip. Along the shore southwestward the Carboniferous rocks are exposed almost as far as the mouth of a small brook, although frequently intersected along the bedding by pegmatite veins, often of considerable size. The more western courses are decidedly black carbonaceous shales. Before reaching the mouth of the little stream pegmatite occurs in great abundance.

About three-fourths of a mile south of Watsons Pier the coast makes a projection a little like the Bonnet, but smaller. This projection is formed by a rock looking in general like an ordinary light-colored granite, though showing pegmatitic veining and pegmatitic structure in blotches. West of the south end of this projection, and directly west of Whale Rock, there appears dark shaly rock, with some sandstone The sandstone is in places made up of very coarse quartz grains. Some of the shaly rock is very carbonaceous; strike N. 25° E., dip about vertical. Along the more southerly trend of the shore the Carboniferous rock is at first not exposed, although the occurrence of the pegmatite offshore only in the form of narrow dikes indicates the presence of the intersected clastic rocks, but farther south there is seen a conglomerate with pebbles from one-fourth to one-half an inch in diameter, quartzitic as a rule. The angle northeast of the Clump Rocks is formed by pegmatite.

The western of the Clump Rocks at the light-house is formed by an ordinary granite rock of medium grain with pegmatitic dikes and blotches. It includes near the top a mass of Carboniferous quartzitic sandstone, with very many biotite flakes. The included piece still has an eastward dip. At the water's edge on the west side is a long mass of Carboniferous rock of



COARSE PEGMATITES OF WATSONS PIER, RHODE ISLAND

considerable length, of darker and finer grain, showing the carbonaceous character of the inclusion. Strike of the same, N. 16° E., dip 45° E.

A third of a mile northwest of the Clump Rocks the pegmatite incloses a small fragment of Carboniferous shaly sandstone.

The eastern and much larger hill of Boston Neck shows frequent pegmatite exposures on the eastern side toward the top, directly west of Bonnet Point, and over a considerable area near its southern termination, south of Watsons Pier. It is more probable, however, that this hill is composed of pegmatite and Carboniferous rocks in frequent alternation than that it is underlain by pegmatite alone. The more western hill contains numerous exposures of granitic rock verging into pegmatite, near the Narrows, and a few exposures of the same rocks on the western side.

On Little Neck there are frequent exposures. They were not carefully searched, but all the rocks examined were granitic, usually medium grained, whitish or reddish, cut by pegmatite dikes or containing blotches of pegmatite, the pegmatite being unusually coarse just west of the north end of Beach Pond, where the mica plates are at times 6 inches broad.

Between the two old wharves at Narragansett Pier, east of the Casino, the Carboniferous rock is seen again, included as a very large block in the granitic rock. It is chiefly sandstone, decidedly quartzitic, with white and black mica, the latter more common along certain layers parallel to the stratification. There is considerable crumpling in this rock, especially toward the south end. The rock contains also a layer of conglomerate. The pebbles are so much drawn out and flattened along the plane of schistosity that they appear as indistinctly bordered whiter blotches on the general rock surfaces; but transverse to the schistosity, especially along their shorter diameter, their outline is often fairly distinct. They are usually one-fourth of an inch thick, rarely more than a third of an inch, with a width of 1 to 1½ inches and a length of 3 to 4 inches. No one who had followed the Carboniferous series in the order here indicated would fail to recognize the Narragansett Pier exposure as belonging to this series.

The granite at the pier is reddish and often pegmatitic. The exposures were followed southward for 2 miles along the shore. It is undoubtedly the same granite as that on Little Neck and Boston Neck. Since it includes fragments of the Carboniferous series, as well as intersects the strata of this series, it must be of more recent age. This subject is further discussed

in the chapter on the arkoses and conglomerates of the Narragansett Bay region (Chapter X).

WEST OF THE COVE AND PATTAQUAMSCOTT RIVER.

Pattaquamscott River and the cove toward the southwest were once probably occupied by the Carboniferous series, now removed by erosion, excepting along the western side of the valley formed by the eastern side of Tower Hill. At the southern end of this hill, north of the railroad, the rock is very quartziferous and schistose. The schistosity strikes N. 80° E. and dips 60° N. In certain layers the rock is full of pebbles, chiefly quartzitic, but with also some granitic ones. The pebbles are very much elongated and flattened, as at the pier exposure. Farther northeast the conglomerate pebbles are still more drawn out. The pebbles usually are white, bordered by a greater accumulation of black mica than is found in the general mass. As the lengthening of the pebbles continues, a point comes where there appears an alternation of whiter and darker thin bands, in which only a person familiar with such studies would still recognize the pebble. This limit has here been reached. Farther down the hillside some of the larger quartzitic and granitic pebbles are less drawn out, and can easily be recognized. Some of the larger ones are 1½ to 2 inches long. Below the hotel, farther northeast, the rock is well exposed. From the southern end of Tower Hill, as far as the hotel, the Carboniferous rocks are frequently cut along the schistosity by dikes of ordinary granite, and also by the pegmatite phase of the same, into which it merges in some places, while at others the contrast is sharp. The result is a rapid alternation of clastic Carboniferous rock with these granitic and pegmatitic dikes, especially well shown below the hotel. The alternation of Carboniferous rocks and the pegmatitic granite occurs for a distance of 2 miles along the east side of Tower Hill. The schistosity dips westward. Going northward no more Carboniferous rocks are encountered until the old plumbago mine, a little over half a mile south of Bridgetown, is reached. Above the mine is a good exposure of a dark, very micaceous, and probably graphitic schist. The strike of the schistosity here is N. 5° E. and the dip 70° E. Farther down the hillside a great quartz vein includes scattered and brecciated remnants of the Carboniferous series; among others, fragments of genuine black plumbago, unctuous to the touch. The main body of Tower Hill,

and its northward extension, McSparran and Hammond hills, is made up of the granite, reddish, medium to finer grained, diked and blotched by pegmatite. Occasionally there is a slight tendency toward schistosity in some of the outcrops.

The valley of Indian Run was at one time probably also occupied by Carboniferous rocks. Near the southern end, toward Peacedale, several exposures of the Carboniferous still remain. Directly east of Peacedale, on the southern side of a steep hill, partly wooded, a strongly metamorphosed rock, possibly belonging to the Carboniferous series, is exposed; strike N. 50° E., dip 70° SE. The rock here has a decidedly gneissoid structure, being composed of white quartz with white and black micas and some other black mineral. The darker minerals are often arranged in layers between the lighter-colored ones. Some of the whiter streaks may represent original pebbles. Apparently some of the larger granitic and quartz-vein pebbles have suffered less drawing out and remain more recognizable. These exposures are at the extreme limit of macroscopically recognizable clastic rocks. Farther up the hillside occurs a reddish porphyritic gneiss, apparently representing a granite with phenocrysts of feldspar. All rocks named are cut by the regular reddish granite with pegmatite blotches and dikes. Similar exposures of the gneissoid—possibly Carboniferous—rock occur where the road east from Peacedale crosses Indian Run.

On Rose Hill, west of Mooresfield, occurs the granite with pegmatitic variations. Apparently the more gneissoid form, with crushed and stretched porphyritic feldspars, also occurs here. Directly northward $2\frac{1}{2}$ miles, on Congdon Hill, more granite occurs. Some of it is the ordinary type of these regions, with pegmatitic phases. Other portions appear gneissoid, and some exposures here are similar to the gneissoid Carboniferous schists east of Peacedale.

It is evident that the extreme western limit of rocks whose clastic origin can readily be recognized has here been reached. This is not equivalent, however, to asserting that the original western limit of the Carboniferous deposits of the Narragansett Basin in this direction has been attained. It is probable that they once extended farther westward, but in the limited time at the writer's command detailed study of these more western areas was not possible.

FROM SAUNDERSTOWN TO WICKFORD.

North of Saunderstown the same series occurs that is exposed along the shore from Saunderstown to Narragansett Pier. Except for a short distance between Caseys and Greenes points the exposures are all confined to the more inland districts. Most of the outcrops are sandstones. The softer, more finely grained, and more carbonaceous sandstones, almost possessing the character of shales, are more rarely seen than south of Saunderstown. This may mean that unequal erosion has left their former line of outcrop beneath the present level of the soil, or that they were rarer in the area northwest of Saunderstown. The facts noted in the field point rather to a diminution in the frequency of the darker, shaly strata. The rocks corresponding best to the shale seem to be less carbonaceous than southward, and merge into fine-grained sandstones only sufficiently carbonaceous to give them a very dark, but rarely a really black, color.

Where first exposed north of Caseys Point, the dip of the sandstone is about vertical. At the beginning of the continuous exposures the strike is N. 6° E., dip 35° E. The coarser sandstone is very quartzitic, white, with abundant white mica, spotted with a more scattered black micaceous mineral. The cross stratification is often marked (Pl. XX). This sandstone contains frequent thin conglomeratic layers, with pebbles up to $1\frac{1}{2}$ or 2 inches in diameter. The pebbles are usually quartzitic, occasionally granitic. Interbedded with these rocks are darker, more carbonaceous, finer-grained courses. Going northward toward the quarry a rather thick layer, more carbonaceous than usual in this more northern area, borders the shore. Here the strike is N. 10° W., dip 45° E. A pegmatite dike cuts the rock parallel to the strike. A darker, finer-grained, more ferruginous dike also seems to occur. The alternation of finer-grained, more carbonaceous rock, coarser white sandstones, and occasional thin pebble layers continues as far as Hazzard's quarry. Here the strike is N.° 8 E., dip perhaps 60° E.

From this quarry westward, as far as the angle in the road connecting Saunderstown and Hamilton, there are a number of good exposures on the hillside. The large exposure at the quarry consists almost entirely of white sandstone. At the house on the hillside there occur wide layers of a dark-blue, very fine-grained shaly rock, which takes the place of the much more

CROSS-STRATIFICATION IN PEBBLY SANDSTONE OF KINGSTOWN SERIES, DEVILS FOOT LEDGE, KINGSTOWN, RHODE ISLAND

carbonaceous shales south of Saunderstown; dip, 50° E. Farther west the sandstone contains conglomeratic streaks; dip, 65° E. Still farther west is sandstone with a few scattered pebbles, rarely 2 inches long. The coarser sandstones contain fragments looking like altered clastic feldspar grains, obtained from some more ancient granitic area. Coarser and darker fine-grained sandstones occur westward as far as the road angle mentioned above. The next exposure of the section lies on the western slope of Barbers Height, on the north side of the road toward Hammond Hill and three-fourths of a mile from the shore; strike N. 10° W., dip 80° E.; coarse white sandstone and darker finer-grained rock with black mica. On the south side of the road, hardly a quarter of a mile farther westward, both kinds of sandstone occur. The coarser contains granite pebbles. A pegmatite dike is here poorly exposed.

Northward along the trend of the hill called Barbers Height the coarse white sandstones and dark finer-grained rocks continue to be exposed. The darker, more carbonaceous, fine-grained shaly rock has a slightly purplish tinge at several points along the roadside. The most marked change toward the northern end of the height is a more north-westerly strike, corresponding to the change in the trend of the granite hill on the southwest, and a much lower eastward dip, usually not exceeding 40° E.

At the angle of the road, $1\frac{1}{4}$ miles south of Hamilton, on the way to Hammond Hill, there are numerous exposures. The dips are usually about 30° E. The strikes are northerly, but variable. No sharply defined bedding planes assist in determining the plane of stratification. A pegmatite dike occurs behind a barn near the southeastern end of the set of exposures. It is one of the most northerly of these pegmatite dikes in the Carboniferous area. About a quarter of a mile east of this locality the strike is N. 10° W., dip 40° E., well shown. Northward less than a quarter of a mile, at the angle of the road, the strike is distinctly west of north, how much is unknown, perhaps N. 20° W., dip 30° E. Northeastward in the field the strike is N.-S., dip 30° E., well shown. The last exposure, lying north of a stone wall, shows a change of strike to N. 25° W., dip 20° E., well shown by dark carbonaceous, fine-grained, shaly rock overlying the coarser whiter sandstone. Another of these marked changes of strike

toward the northwest is seen northeast of the last exposure, near the northeast end of the most northerly walled field on the hill. Here a strike of N. 12° W. becomes N. 40° W. in a very short distance northward. The dip is steeper than usual here, 60° E. The most northern exposures, near the cove, show a northwesterly strike and an eastward dip of about 35°, as nearly as it can be determined.

The next set of exposures westward is at the angle of the road a little over a quarter of a mile south of Hamilton. Here the strike is N. 30° W., dip 65° E., rather well shown by the contrast of the dark finer-grained and the coarser white sandstone. The latter, in places, contains very small pebbles. West of Hamilton a quarter of a mile a road leads northwestward and connects with another road leading to Wickford. Along both sides of the first road exposures are numerous. One near the road gives a strike of N. 40° W., dip about 45° E.; there is contortion along the strike. Along the ridge at the western end of a row of houses, south of a pond, the strike is N. 12° W., changing to N. 20° W., dip apparently 50° to 60° E. North of this pond considerable coaly fine-grained rock is shown on the south side of the road, with apparently a nearly horizontal bedding and a slight dip northeastward. On the eastern side of the connecting road to Wickford there are good exposures upon a rather high hill. Toward the north, one exposure exhibits a strike of N. 18° W., dip 60° E., finely shown by a very carbonaceous, fine-grained shaly layer in the coarser white sandstone. In this entire series of rocks the coarser white sandstones prevail; they contain but few pebbles and these are always small. Finer-grained, more carbonaceous layers, with ottrelite locally, occur here more frequently than to the westward. West of Hamilton, toward Indian Corner (marked Allenton on the maps), about halfway between the two villages, a large exposure on the south side of the road shows a strike of N. 20° W., dip 45° E., well exhibited by alternating dark fine-grained rock and white coarse sandstone. Around Indian Corner, exposures, chiefly of coarse sandstone, often with pebbles, are numerous. The strikes are variable, being on the average N. 27° W., dip 30° to 45° E. A little over half a mile south of Indian Corner, in the roadside and northeast of the house, a bluish Carboniferous sandstone shows strike N. 45° W., dip 50° E. This occurrence agrees very well with the apparent northwesterly trend of the line of granite

bordering the Carboniferous field in this direction from Hammond Hill beyond Congdon Hill.

As already stated, the exposures from Saunderstown to Wickford and westward are a northward extension of the series which is developed to the southward as far as Narragansett Pier.

FROM WICKFORD TO EAST GREENWICH.

Northward of Wickford, as far as East Greenwich, the rocks last above described continue to occur, but there is a marked change in their dip, the general dip being westerly, except on Potowomut Neck, where the strike swings around to the northeast, and more or less irregular folding gives both northwesterly and southeasterly dips.

The most western exposures occur about a mile south of Davisville, along the railroad. Here a bluish sandstone, with conglomeratic layers and carbonaceous color banding, shows strike N.-S., dip 45° W. East of these exposures, about half a mile west of the road between Wickford and East Greenwich, on the north side of the connecting road toward Davisville, abundant exposures show strike N. 12° W., dip 70° W. Along the western side of the main road itself exposures are frequent for a distance of about 2 miles north of Wickford. One of the more southern exposures, on a hill west of the road, shows strike N. 40° E., dip very steep, about vertical, perhaps slightly east. A quarry near the northern end of this series shows a strike of N. 18° E., dip 85° W., well marked by narrow carbonaceous color banding in a coarse sandstone. North of this quarry a short distance a road goes eastward; $1\frac{1}{3}$ miles eastward along this road a road goes northward. Along this road occurs an exposure of a very carbonaceous, possibly ottrelitic, sandstone with strike N. 20° E. and dip westerly. About $1\frac{1}{3}$ miles directly north of this exposure, on the southeast side of a road, there is sandstone with thin pebble layers. There seems to be a very low northerly dip of the rocks here, nearly horizontal. The most easterly exposures occur west of Clarks Point, along the west side of the road, as far north as Halls Creek. The strike on the average is N.-S., the dip 20° W. About $1\frac{1}{4}$ miles northwest of Allens Harbor and 1 mile south of Potowomut River there is a large exposure north of a schoolhouse at the road corner. The rock here is largely of the fine-grained,

black, carbonaceous type, especially along the northwestern side of the exposure, interstratified with which is coarser white sandstone. Both rocks contain garnets, and the shaly rock is ottrelitic. Strike N. 23° E., dip about 45° W.

Toward the western end of Potowomut Neck, near a residence north of the road, are numerous exposures of sandstone with strike N. 50° E., dip 35° N., on the western end of the exposures. Toward the eastern end of the neck a series of exposures extend from the Potowomut Rocks directly southward nearly to the Potowomut River. The general trend of the rocks is northeasterly, but it is evident that considerable irregular flexuring or folding has taken place, so that the strikes are very irregular, and the dips are both northerly and southerly, according to the particular locality observed. While therefore unsatisfactory for purposes of stratigraphy, these exposures are still worthy of close examination, because they show some very interesting phenomena connected with the shearing of these rocks more or less perpendicular to the bedding and the consequent interpenetration of the frayed surfaces of the adjoining layers. The more carbonaceous layers in the exposures west of the house north of the road show garnets and other minerals, the products of metamorphism; one of these minerals occurring in the rock is columnar, black, with frayed expanded ends. While a large part of the rock exposures are coarse white sandstone or finer-grained black shaly rocks, as in the rest of the series described in this area and southward, yet there is a very large exposure, west of the buildings north of the road, of a greenish shaly rock, spotted with the stained marks caused by the weathering of some pyritiferous mineral, which is very unusual in the series. The strike at the Potowomut Rocks seems to be N. 50° E., dip apparently steep northwest.

WESTERN BORDER OF THE CARBONIFEROUS BASIN, FROM EAST GREENWICH TO NATICK AND NORTHWARD INTO CRANSTON.

The present western border of the Carboniferous basin of the Narragansett region extends from East Greenwich southwesterly, west of Davisville and Wickford Junction. At East Greenwich the pre-Carboniferous rocks form the steep hillside above the town. At a road corner near the top of the hill, in a line almost directly west of the Potowomut Rocks, these more ancient rocks are well exposed in a quarry. The rock here is

very fine grained and white, with minute black specks. The cleavage planes lie E.-W., dip low northerly. The western border of the Carboniferous basin probably follows the steep hillside from East Greenwich to Coweset, and thence for some distance the northern side of Drum Rock Hill. The presence of (1) granite exposures near the southeastern end of the hill, half a mile west of the southern end of Gortons Pond; (2) a fine exposure of the quartzite and schist series at the northern end of the same hill, hardly a sixth of a mile east of Natick; (3) an exposure of the same series on the western side of the hill, a quarter of a mile south of the last locality, and (4) a series of exposures southwest of the third locality, along the road leading directly south from Natick, in order—quartzite, then granite, then quartzite again—tends to show that the present western border passes only a quarter of a mile west of Gortons Pond and thence northwesterly to Natick.[1]

From Natick northward the basal rocks of the Carboniferous series form the steep hill front for a distance of at least 2½ miles, while the eastern line of outcrops of the pre-Carboniferous series can be traced far northward into Cumberland.

The greatest interest in this border line, however, centers in the comparatively small stretch of 2½ miles from Natick northward, since here the Carboniferous beds can be seen resting on the pre-Carboniferous series, the basal beds containing very many angular fragments and rounded pebbles derived from the older rocks, the material of these pebbles varying with the character of the underlying rocks immediately adjoining. All gradations may be seen, from the most angular fragments to well-rounded pebbles.

The quartzite-schist series is well exposed along the north side of Bald Hill northward as far as Natick, especially west of the town. Near the center of Natick a road leads up the very steep hill west of the town. Just north of the beginning of this road is a church, below which the quartzite series is exposed. Ascending the road for a distance of perhaps 100 feet, turning northerly into a group of houses, the observer discovers a fine exposure of the Carboniferous base resting against the quartzite on the west.

[1] The evidence leads me to believe that the margin of the Carboniferous field originally lay much farther to the west. It is likely, indeed, that it may have merged with what is now the Worcester Basin.—N. S. S.

The bed is rather bluish and dark in color, and contains very angular and rather separated fragments of white quartzite, producing a striking effect on account of the differences of color and the consequent distinctness of outline of the fragments. This effect is heightened by the comparative rarity of the bits. From this cluster of houses a short footpath leads west up the steep hill to the house of Mr. Alexander McTeer. Northeast of his house an equally striking exposure is met, the rock here being a great mass of very distinctly outlined, very numerous angular fragments of quartzite embedded in a slightly darker cement. From this point the basal Carboniferous conglomerate forms the northeastern face of the hill, the underlying quartzites being often well exposed just southwest of the brow of the hill. It often requires close observation to distinguish quartzites, where brecciated in situ, from the overlying breccia-conglomerate series which forms the base of the Carboniferous. Southwest of the road corner, where the present western border of the Carboniferous area makes a sharp curve toward the east of north, the underlying beds are of a peculiar greenish rock, often seen northward, as far north as the Cumberland district, where it is copper bearing. The quartziferous basal layer with angular fragments lies west of the road. At the edge of the roadbed southwest of the road corner mentioned, on the east side, the overlying carbonaceous black shaly rock is exposed, dipping under a coarse sandstone. Strike N. 30° W., dip, as might be expected, 50° E. The presence of this carbonaceous bed so near the border of the Carboniferous basin, and so near the base, is very interesting, especially since the basal bed is so conglomeratic.

The basal quartzitic conglomerate beds are well exposed west of the road north of the road corner already mentioned. They rest here on granite. There evidently is a sharp curve in the border line. The exposures can be followed back of the house through the woods for a sixth of a mile. At one exposure along the roadside the basal bed contains granite pebbles over a foot in diameter. After this the basal series must be followed along the east side of the road through the woods. Here the rocks are a coarse quartzitic sandstone. Pebbles are not numerous, and as a rule they are rather small. The sandstone can be readily followed through the woods to a fine waterfall, the existence of which would not be suspected from the road. Here it is well exposed; strike N. 40° E., dip 60° E. Thin

carbonaceous bands assist in showing the bedding. The series can be traced into the open field northward. Here it rested formerly upon granite and schistose rocks. An exposure in the open district, just east of the road, isolated from the rest, shows among the pebbles also one derived from the gneissoid schist, an interesting occurrence, since, in spite of the abundance of the schistose rock in the vicinity of the basal sandstone and conglomerate series, pebbles from the schist are rarely found. The schist does not seem to have furnished many pebbles, but broke up into a fine grit on aerial degradation and furnished part of the finer material of the overlying series. The granites also must have been considerably decayed. The alteration products of the feldspars drifted farther away from the land, but the quartzitic material remained nearer the shore to form the cement of the basal conglomerates and the overlying arkose and sandstones; but pebbles of granite are by no means uncommon, although quartzite, on account of its greater durability, formed the predominating pebbles of the basal conglomerates.

The basal series of arkoses and sandstones, with scattered pebbles, may be traced east of the road to a point about a mile north of the road corner, where the sharp bend in the western border of the Carboniferous area occurs. Here the basal beds rest upon a varied group of rocks—gneissoid schists, a peculiar greenish rock of the type found in Cumberland, and granite. North of this point the basal series crosses the road and follows it along its western side, resting upon granite as far as the next road corner northward. A house stands east of the road near the point where the basal series crosses the way. A short distance north the road crosses a stream. Up the stream westward, in the woods, the basal series, only moderately conglomeratic with granite pebbles, may be seen well exposed. A quarter of a mile from the northern road corner the very steep hillside is formed by white coarse sandstone, with layers of small pebbles and occasional scattered angular pebbles, some of them as much as 9 inches in diameter; some of the latter are granite. The underlying rock is granite. From this point the basal series can be followed to a short distance south of the road corner, behind a barn, where, in an open field, there is a fine exposure of the series overlying the granite; conglomerate layers are frequent, often with large pebbles, some of these of granite, the greater part of quartzite. From this point the basal series passes northerly to a point west of the road corner, a

third of a mile distant. This exposure, along the western road, is very interesting on account of the extreme lengthening and flattening which many of the pebbles have undergone in consequence of shearing. The pebbles consist of quartzite and granite. Those of larger size, embedded in the softer cement, have been less sheared and can be more readily recognized. The basal conglomerates continue to be shown along the western side of the road to Knightsville, resting toward the south upon granite, and farther north upon schists. Where the basal series fails to be exposed, the western border of the Carboniferous area can still be recognized by the steep hillsides formed by the older pre-Carboniferous rocks.[1]

ROCKS EAST OF THE WESTERN BORDER OF THE CARBONIFEROUS AREA IN WARWICK AND SOUTHERN CRANSTON.

The basal series of rocks are quartzitic sandstones of white color. Overlying them are bluish sandstones and coaly shales. The coaly shale east of the great bend in the western border of the Carboniferous area northwest of Natick has already been mentioned. At the northern end of the village, along a connecting road west of the river, blue sandstone with darker courses, and a few conglomerate layers with small pebbles, are well exposed. Strike N.-S., dip 45° E. A sharp change in the strike must take place in Natick, as already indicated in connection with the description of the border line.

Along the road from western Pontiac northward a number of exposures occur. They indicate the presence of bluish sandstone, with small pebbles, and bluish-black ottrelitic shaly rock along the western side of the hill east of the New York, New Haven and Hartford Railroad. The strike is northerly and the dip 10° E. The entire hill and the valley on the west is probably underlain by an alternating series of blue sandstones, often with conglomeratic layers and bluish-black or black ottrelitic shales. Coaly beds are common on the east side of this line of hills, and were formerly mined farther northward, at the well-known mines northeast of the Reform School on Sockanosset Hill, on the east side of Rocky Hill, which geologically is a continuation of Sockanosset Hill, and still farther northward in the Valley Falls district. This series of coaly rocks not far above the base of

[1] In my opinion this cliff is not an old shore escarpment, but is due to the deformation of the old floor of the basin and the subsequent erosion of the soft beds which lie against it.—N. S. S.

the Carboniferous, extending along the western border of the Carboniferous field, often presenting workable coals, was well recognized by early investigators of this district, many of the mines dating back more than fifty years, though all save one, that at Valley Falls, are now totally abandoned.

The most southern exposure on the east side of Sockanosset Hill is half a mile south of the State almshouse, near the railroad. The medium-grained sandstone is bluish; the coarser, whitish. Quartz pebbles up to $1\frac{1}{2}$ inches in diameter occur in the conglomeratic layers. The series dips 10° NE. In front of the almshouse are black ottrelitic shales. Toward the northeastern side of the building, and thence for a rather long distance through the grounds, more sandy bluish sandstones, occasionally conglomeratic, occur, merging into fine-grained rocks, and these into greenish and bluish shales, in part ottrelitic. The strike of the series is north-south, carrying the rocks east of the Reform School. The dip is 20° E. The finer-grained rocks and shales rather predominate in this series, and may also be seen near the almshouse, east of the road. In the vicinity of the Reform School and of the reservoir, exposures of bluish sandstone and ottrelitic shales occur. The coaly beds, including the workable coals, occur halfway down the eastern hillside and thence down into the valley region. The strike of the rocks is north-south, the dip low east—usually 20° E.—except toward the mine, where the dip, according to the miners, increases to about 50° E. If this is true, it is a local flexure, the dips eastward being low again. The existence of such a flexure seems, however, to be supported by indications northward, the dip at Wayland Station, on the northwest side of Sockanosset Hill, being 20° to 30° E., while on the eastern side of Rocky Hill it is 40° to 70° E.

Eastward of the Pawtuxet River, however, the exposures show low dips again. Along the railroad north of Hills Grove Station, black, often coaly, shales lie almost horizontal. North of the road corner east of the station a quarry shows abundant sandstone with a northward dip of about 20°. A third of a mile north of the station, west of the railroad, abundant sandstone with conglomeratic layers shows a northeastward dip of 20°. The sandstone contains stems of calamites, longitudinally coarsely corrugated stems, undeterminable flattened stems, and leaf-like impressions, 1 or 2 inches wide and 15 to 30 inches long. Similar forms may be recognized

in the Silver Spring region. A quarter of a mile southwest of Norwood Station, west of the railroad crossing, numerous exposures of sandstone having a low easterly dip occur.

WARWICK NECK.

Eastward of Hills Grove and Norwood stations there are no exposures in Warwick until Warwick Neck is reached. In the railway cut west of the main road passing along the length of the neck, black carbonaceous shales and some sandstone courses dip in a northerly direction. West of the same road, a quarter of a mile south of the highest point of the neck, sandstone is exposed. East of the highest point of the neck the hill-sides, sloping steeply to the shore, show frequent exposures of sandstone dipping at an angle of about 40° E. Nearer the foot of the hill carbonaceous dark shales make their appearance. The sandstone continues to be well exposed for about a fifth of a mile southward. Northeast of these exposures, north of a small pond where the shore turns northeastward to Rocky Point, black shales dip low eastward. Corresponding bluish-black shales and fine-grained sandstones are found a quarter of a mile northward, along the road to Bay Side. There occur in succession, eastward: Sandstone, forming the south end of the high ridge east of the road last mentioned; conglomerate, forming the middle and northern part of this ridge; sandstone, exposed at the northeast of the northern end of the ridge and on the western side of the main hill occupied by the Rocky Point booths; conglomerate, forming the eastern part of this hill, and a solitary exposure farther northward, and then various sandstone layers as far east as the point, the intervening courses not being seen, being probably some softer shale. The strikes of the exposures at Rocky Point are N. 10° W., dip 20° E. Many of the pebbles in the conglomerates at Rocky Point are of considerable size.

A short distance north of Sand Point, on the neck, sandstone and conglomerate are exposed dipping toward the northwest. At the southern end of Warwick Neck, near the light-house, and for a short distance westward, black carbonaceous shales and some sandstones are exposed dipping in general northward, but suggesting in places a sort of contortion of the rocks by a force acting in an east-west direction.

CHAPTER IV.

THE NORTHERN SHORE OF THE BAY.

PROVIDENCE RIVER AND EASTWARD.

The geology of the area directly east of Warwick, on the eastern side of Providence River, in Barrington, is not well disclosed by outcrops.

It will be remembered that the strike of the exposures west of Rocky Point was a little west of north and the dip low east, about 20°. The strike would carry these rocks a little west of Pawtuxet village. At the mouth of the Pawtuxet River sandstone is exposed, and the neck upon which a part of the village is built is apparently underlain by a similar rock. This sandstone could easily belong to the Rocky Point series, if the Rocky Point exposures be correlated with the exposures on the eastern side of the river.

These eastern exposures extend from East Providence, north of Watchemoket Cove, along the shore as far as a point directly west of Riverside Station. This section is chiefly sandstone, although at certain horizons conglomerate layers are abundant. In the region east of the Pomham rocks a local syncline can be detected. Immediately east of this syncline there are a number of exposures with westerly dip.

Half a mile east of the Pomham rocks there are three ridges in obliquely overlapping order, from south to north. The middle ridge shows a westward dip of 30°. The middle and northern ridges contain considerable conglomerate. The southern ridge consists chiefly of sandstone. Isolated exposures occur north of the series of ridges. No perfectly satisfactory stratification planes can be made out in the northern and southern ridges. This leaves room, of course, for the supposition that eastward dips may occur in them and that we have here a series of closely folded anticlines and synclines.

The nearest rocks with well-defined dips are shown in a set of large sandstone exposures a moderate distance east of the three ridges named. These eastern sandstone exposures show an undoubted westward dip of 40° to 45°. This is indicated both by the presence of conglomeratic layers and by the distribution of a large number of plant stems. Owing to the two distinct cases of westward dips east of the Pomham local syncline, one in the middle ridge, the other in the sandstone quarried east of this ridge, a general synclinal structure of this region seems a possibility, although the probability of a series of folds here must not be excluded.

With this possible structure in view, the conglomerates and sandstones west of Rocky Point and east of the Pomham rocks are correlated as belonging at least to the same general series, above the rocks found farther westward in Warwick. In other words, these rocks are believed either to overlie the Saunderstown sandstone series as a distinct superior formation or to form the summit of that series.

If this be true, the sandstones and conglomerates east of the Providence River must dip southeastward on approaching Rumstick Neck, in order to underlie the exposures south of that neck, if the shales of the latter are to be correlated with the Aquidneck series. The exposures within the writer's field are inadequate to settle this question.

RUMSTICK NECK.

The first exposures eastward of Providence River, in Barrington, occur along the southeastern shore of Rumstick Neck. About a quarter of a mile west of the southern end of the neck lies Long Ledge, made up of Carboniferous sandstone with strike N.-S. and dip 30° E. A little southeast the same sandstone is exposed in Rumstick Rock with strike of E.-W. and dip 45° N. The sandstone here contains impressions of plant stems—one like calamites, the others coarsely ridged. They are of the same type as those found at Hills Grove, east of Providence River, north and south of Silver Spring, in the quarry east of the range of three ledges, northeast of Riverside, and elsewhere. On the shore itself is greenish shale of the same type as that belonging to the shale series northward. It seems to have a strike of N. 20° W., dip 30° E., and evidently overlies the sandstone of the ledges.

POPASQUASH NECK.

A long ridge of sandstone lies northwest of Ushers Cove, first trending northward, then northeast, and then more northerly again. It is of bluish color. No satisfactory strikes and dips could be determined, although the exposure is large.

BRISTOL NECK.

CARBONIFEROUS AREA.

The lowest Carboniferous exposures on the neck consist of coaly black shales, opposite the Brothers and Deyers Rock, where the railway begins to turn toward the southeast, leaving the shore. The strike seems to be N. 10° W., dip 40° E. Species of Annularia and ferns occur in the rock. The same black shales are found three-fourths of a mile farther southeast, in the railway cut, where the strike is northwest and the dip northeast. Above this coaly shale, exposed along the shore a quarter of a mile north of the Brothers, lies sandstone containing black shaly layers showing a strike of about N. 10° W., dip 40° E. Northeast of these shore exposures, east of the railroad, is a high ridge of bluish sandstone, whose strike and dip can not be determined, although the dip is probably eastward and the strike probably of such a character as to connect this exposure with a set of sandstone exposures farther south. This set of sandstone exposures begins on the hillside east of the Brothers and of the railroad. It strikes at first about N. 20° W., dipping 20° E. In the exposures southeast of this locality the strike becomes more and more nearly east-west until, in a quarry just west of the Warren-Bristol road, it is about N. 85° W., with a dip of 20° N., the strike becoming perhaps N. 80° E. just before reaching the road.

Above this sandstone, toward the north, lies conglomerate. The most conspicuous exposure is less than half a mile south of Jacobs Point, just east of the railroad. The conglomerate here has a thickness of at least 20 feet. Its dip is low eastward, as may be seen by sandstone layers near its northern end. The pebbles are of sandstone and are often 6 to 10 inches long. The other conglomerate exposure lies 1,500 feet southward, indicating by its position relative to the other exposure a strike of N. 10° W. It forms a small knoll in an open field. East of the region between these two

conglomerate exposures lie green shales of the same type as those belonging to the shale series southward. The green shales are exposed chiefly along two low ridges, the first one-third of the distance from the line of the conglomerates to the Warren-Bristol road, and the second about two-thirds of that distance. No strike and dip could be determined. The cleavage is marked and the planes are numerous. Notwithstanding the absence of definite stratification the dip is undoubtedly eastward, corresponding to the dip and strike of the rocks below and above. The green shales therefore here overlie a very coarse conglomerate, but the conglomerate seems to have had but a very limited extension. Overlying the bluish-green shale is a bluish sandstone bed, the lowest part of which is conglomeratic, the pebbles being of small size. The exposure occurs east of those last mentioned, east of the Bristol-Warren road, and forms the summit of the hill. The strike can not be well determined, but seems to be about N. 45° W., dip 45° E. Eastward the sandstone becomes rapidly less coarse, then very fine grained, and is finally overlain by the bluish shale which forms the exposures over the remainder of the area of the neck north of the pre-Carboniferous granite region. This shale is well exposed west of the road half a mile farther northward, east of the road in the valley, and along the entire western margin of the hill just beyond for half a mile southward. It is also exposed near the summit and along the northern and northeastern sides of this hill, which may be recognized by its height of 120 feet, as indicated on the map. At the second angle of the road toward the northeast of the hill the shale is very black and carbonaceous. Farther eastward, east of another main north-south road, the greenish-blue shale is again abundantly exposed directly east of the summit of the 120-foot hill. The shale is also well exposed in quarries and on the hillside less than a mile farther northward on the eastern side of the hill, near the top. In all this area, excepting in the cases already described, the Carboniferous is represented by the shale series, varying from bluish green to greenish and bluish, sometimes dark blue and black.

GRANITE AREA.

Granite occupies the southern part of Bristol Neck. A coal bed was once exposed in the western part of Bristol only a few feet above the harbor. It was said to strike east of north and to dip about 48° W. The

coal was said to be of excellent quality.[1] Granite is exposed at the north end of Walkers Cove. Thence it occurs along all the more elevated streets of the town. North of Bristol the outcrops extend for about a mile a little east of north, and then eastward for another mile. The nature of the rock which underlies the area along the shore east of the very large quartz veins on the east side of Mount Hope, and thence northward at least for a mile, is unknown, since there are no exposures. At Walkers Cove, and numerous other points in the granite area, the granite is coarsely porphyritic, containing phenocrysts of feldspar an inch and more in diameter. Still more frequently it does not contain the feldspar phenocrysts. Gneissoid structure, in consequence of shearing, is very common, the shearing having been as a rule in the direction N. 30° to 40° W. This agrees fairly well with the direction of shearing in some of the exposures south of Common Fence Point, north of the railroad, on Aquidneck Island. A very fine-grained pinkish rock occurs in places, especially in the valley northwest of Mount Hope. This is believed to be an aplitic rock. The western side of Mount Hope is formed by granite. The summit and precipitous eastern side are formed by quartz veins of gigantic proportions, varying from 40 to 80 feet in width. Granite abuts against these veins on the west, but no exposures occur on the east. On the shore northwest of Mount Hope Point a black schistose rock is included in the granite. Its structure is probably the result of shearing in the granite.

This granite may have formed an island in the Carboniferous sea, but no arkose is known to occur at any point on Warwick Neck, and no contacts are exposed between the granite and any clastic rock. Moreover, the Carboniferous shales nearest the granite area do not show either strike or dip, and the cleavage is also discordant with the outline of the granite area. There is, therefore, no evidence of the existence of the granite area as an island in Carboniferous time, although, judging from the history of a similar granite on Conanicut, south of Jamestown, it is extremely probable that it did so exist. Moreover, the granite of the Bristol Neck area and the pre-Carboniferous granite along the east side of Taunton and Sakonnet rivers show features so similar as to make it very probable that they together constitute a geological unit.

[1] This mine has been filled up. Specimens of coal shown me were of the same nature as that from the Portsmouth mine.—N. S. S.

WARREN NECK.

About a mile north of Chases Cove, on Kickamuit River, the shore line is deeply indented and a valley extends thence northward for about a third of a mile. West of this valley are abundant exposures of conglomerate, forming two hills over 60 feet high, the pebbles being rather large, often 1 foot in length. There are very few interbedded sandstones, and these lie almost horizontal or dip slightly eastward. The northern hill lies southwest of the angle of one of the main roads of the neck. Northeast of this angle a low ridge of conglomerate in the open fields continues the exposures, increasing in elevation northward on entering the woodland. Two-fifths of a mile northeast of this ridge, along the railroad, the conglomerate is exposed again, showing a strike of N. 30° W., dip 45° E. Hardly a quarter of a mile eastward the conglomerate has a strike of N. 20° W., dip 30° E. Between these two exposures southward, in the fields, occur others with approximately the same strike and dip. Farther eastward, however, the fairly abundant exposures along the south side of the railroad show, eastward, first, a northeast strike and a western dip, changing rapidly to an almost east-west strike and a northward dip of perhaps 20° to 30°.

CONGLOMERATES AND SHALES OF SWANSEA AND WARREN, NORTH OF THE NECKS.

The road from Coles Station to Luthers Corner leads first northward, then eastward, and then northward again. Just south of the second angle of the road, along the shore, the conglomerate has a strike of about N. 60° E., dip low northward. Northward along the west side of the road are several exposures, the most southern of which has a strike of about N. 70° E., dip about 50° N., the strikes farther north being also decidedly eastward and the dips north. East of these exposures a road leads eastward to Fall River. Where it crosses Coles River there are exposures on both banks. Exposures also border both sides of the river for about a quarter of a mile northward; and southward, below the bridge, exposures are found in the channel and on the west bank. The strike for all of these exposures is about N. 45° E., dip 20° NW. Along the road leading from the western side of the bridge northward exposures are abundant on both sides of the road, show-

ing in general a northeast strike and a northwestern dip. One of the more northern exposures, before reaching the 20-foot contour line, indicating a valley entering the hillside from the east, shows a strike of N. 60° E., dip 45° NW. Continuing on this road northward, and then following the main road toward Swansea village, there are abundant exposures of the conglomerate south of the road, not far beyond the mill pond. Here the strike is about N. 45° E., dip 50° NW. About a third of a mile eastward, at some distance south of the road, the strike is about N. 50° E., the dip northwest. The northwesterly dip is shown by the conglomerate exposures at various points north of Swansea village. The northeastern strike and northwestern dip is also shown by the conglomerate exposures which, beginning on the western side of the pond southwest of the village, reappear on the eastern side, and are exposed again before reaching the main street of the village. Following the road east from Swansea village, and taking the first road toward the north, exposures are found again three quarters of a mile northward, bordering the road on the west. The same strikes and dips can still be recognized, continuing thence northeastward to Taunton River.

The general northeast strikes and northwest dips from the first exposure here described, northeast of Coles Station, along Coles River, through Swansea village, show conclusively that these coarse conglomerates overlie the sandstones and shales farther south and east.

West of the exposures just described, from Coles Station as far as the mill pond, halfway between Luthers Corner and Swansea, the conglomerates dip toward the east, showing a synclinal structure over this area. The easterly and northeasterly dips along the railroad, half a mile west of Coles Station, have already been mentioned. A little west of north of Coles Station, directly west of the first strong bend of the road already described, conglomerate is exposed at the margin of the woods, with a strike of about N. 65° W., dip about 30° NE. The conglomerate is here overlain by sandstone merging into a fine-grained shaly rock. Northeastward, in the fields, the conglomerate strikes N. 15° W., and dips east. West of Luthers Corner, for a rather long distance west of the road leading north from Coles Station, are a considerable number of exposures, most abundant north and northwest of the corner. Their strike is in general north-south, dip eastward, often very low. Half a mile north of the bridge across Coles

River, west of the road, and north of the 20-foot-contour valley already noted, are a number of exposures showing in general a strike of about N. 20° E., dip 45° E. Overlying some of the more southeastern of these exposures, on the west side of the road, is a bluish shale. The conglomerate is also exposed east of the road. A third of a mile west of the mill pond a long exposure beside the road west of the bend shows a strike of N. 25° E., dip 30° SE. Overlying the conglomerate is a greenish shale. Just west of the mill pond the strike is N. 70° E., and the dip almost vertical. Northeast of the mill pond the conglomerate exposures northwest of Levins Brook do not vary far from the horizontal, and the synclinal structure can no longer be followed.

The detection of the synclinal structure between Coles Station and the mill pond, and the more horizontal position of the rocks to the northward, is of some assistance in establishing the continuity of this more eastern conglomerate, whose stratigraphical equivalents with the conglomerates in Warren, north of Bristol Neck, and in adjacent parts of Swansea, can be easily determined. Indirectly also it is serviceable in determining the position of the bluish-green shale series of Bristol Neck, as the following notes may show:

The wide distribution of the bluish-green shale series in Bristol Neck has already been noted. From Warren, eastward along the first road leading north, passing east of Belchers Cove and Warren River, bluish shale occurs east of the road a third of a mile south of Kings Rock. Sandstone occurs west of the road, and is also exposed in the northeast angle of the first road leading toward the east. At the latter locality a few stray pebbles of large size are embedded in the sandstone. At Kings Rock, west of the road, on the Massachusetts-Rhode Island boundary line, and also northeastward, east of the road, are large exposures of the bluish shale. The strike of these rocks is about N. 15° E. A mile south of Kings Rock a road leads off eastward to Luthers Corner. Less than half a mile along this road another branches off northward. South of this point a considerable area is covered by bluish and greenish shales, frequently exposed. These shales are also exposed on the eastern side of the hill, east of the road, at several points from a quarter of a mile north of the road corner to half a mile northward, and they are found again a mile north of the road corner, a quarter of a mile east of the road, near the State boundary

line. This set of exposures indicates a strike of N. 15° E. East of the last exposure is coarse sandstone. Toward the northwest and north extend several ridges of sandstone and conglomerate, the most eastern of which can be followed for a mile, as far as the next east-west road. The strike is N. 15° E., dip always eastward, often as low as 20°. Conglomerate and sandstone also occur north of a house some distance east of the road, a quarter of a mile south of the State boundary line. A mile northeast of Kings Rock numerous exposures border the roads eastward and northward. They consist chiefly of sandstone and some conglomerate, dipping eastward, but they also contain greenish shaly layers toward the north end of the series of exposures, where the strike seems to be more nearly east-west and the dip southward.

A third range of bluish shales forms a ridge bearing N. 15° E., both north and south of the road to Luthers Corner, already mentioned. Eastward from this ridge, three-quarters of a mile northward along the first road on the east side, conglomerate is exposed; strike N.-S., dip 70° E. Greenish shale underlies it on the west.

The various exposures north of Bristol Neck, just described, seem to indicate that the bluish-green shales underlie the great mass of conglomerates. These conglomerates are the coarse conglomerates on Aquidneck Island and occur at a considerable distance above the lowest beds of the Carboniferous exposed along the eastern shore line of the basin, from Steep Brook to Tiverton.

GARDENERS NECK.

The eastern line of outcrops of the coarse conglomerate runs through Swansea village, in a northeasterly direction. Beneath these conglomerates, on the east, occurs a series of shales and sandstones. South of the pond southwest of Swansea village, in the bed of the creek which forms its outlet, and in the field between the creek and the road, there are several exposures, chiefly sandstone, but also some more shaly courses, dark blue in color. Southward rather more than a mile, on the road to South Swansea, an exposure of coaly shale occurs south of the road leading eastward to Fall River. This exposure occurs in a digging on the eastern side of the Neck, near the top of the hill. Half a mile farther south, near the base of the hill, toward Lees River, a shaly sandstone or slaty rock

occurs. Its strike is probably N. 40° to 45° E.; this at least is the direction of the line of outcrop. The color is bluish black, or quite black where shaly. This more southern set of exposures occurs stratigraphically beneath the coaly shale lying farther north.

BRAYTONS POINT AND NORTHWARD.

On the northwestern side of the point black coaly shales are exposed. These continue southward as far as the middle of the west shore, where sandstone is frequently interbedded. The strike farther north seems to be N. 50° E., but southward it varies to N. 70° E., and becomes N. 30° E., dip 70° W., near the middle of the west shore. The black shales here contain *Annularia longifolia* and fern impressions. Farther southward black coaly shales continue to be exposed as far as the southern end of the point and its southeastern side. These more southern exposures show a strike of N. 50° E., dip 80° W., or other variable lower angles. The bedding here is not often well shown.

SEWAMMOCK NECK.

A mile and a quarter west of Brayton, on the road from Fall River, crossing the neck, on the western side of the hill, a rather coarse sandstone is well exposed. Its real strike and dip could not be determined, the apparent bedding being probably only cleavage. Similar gray sandstone is exposed half a mile west of Pottersville, north of the road. This sandstone probably underlies the coaly shales of Braytons Point.

CHAPTER V.

THE EASTERN SHORE OF THE BAY.

STEEP BROOK.

Pre-Carboniferous granite forms the steep slopes of the hilly country bordering Taunton River on the east. The western line of outcrop of the granite extends from Steep Brook northward as far as the point where the Myrick branch of the railroad leaves the main line. The line of outcrop of the granite then turns abruptly eastward and follows the southern side of the railroad as far as Washington Mountain. At Steep Brook the granite is well exposed along the sides and in the bed of the brook. The contact with the Carboniferous rocks is not exposed. The lowest exposure of clastic rock consists of conglomerate, strike N. 45° E., dip 30° W. Toward the north, overlying the conglomerate, is sandstone, with a dip of 40° W. Thirty feet west of the conglomerate there was not long ago exposed a narrow coal seam, with coaly slate containing fern impressions. Its strike was N. 15° E., dip 20° W. West of the coaly layer occurs a considerable thickness of arkose, in some places scarcely showing bedding, in others indicating the planes of bedding by color banding caused by more carbonaceous material in certain thin layers. A little of the arkose material exists beneath the coaly layer. The arkose consists chiefly of quartz, derived from decayed granite. The quartz grains as a rule are not rounded. The granite which furnished the constituents of the arkose must have been reduced to a mass of loose material by aerial decomposition, so that the quartz grains were readily washed away in order to form the arkose, while the feldspathic material formed interbedded layers of the impure kaolin, which was once quarried by the owner of the premises for shipment to pottery works. The absence of the arkose and clay material near the base of the series here is noteworthy. Still more important is the conglomerate layer near the base, for the conglomerate, although so near the granite area, does not consist of granite pebbles, but of quartzitic pebbles, often 3

inches long, similar in character to the pebbles in the Dighton conglomerate. The granite from which the arkose and kaolin were derived was too decayed to furnish pebbles, but the quartzitic rocks withstood weathering sufficiently to furnish good pebbles to the basal conglomerates, in spite of probably long transportation.

FALL RIVER.

A still more interesting exposure occurs in Fall River, in Annawan street, halfway down the hillside, behind some mills. The eastern border of the present Carboniferous area extends from Steep Brook along the escarpment bordering Taunton River to this locality in Fall River, with a trend of about N. 32° E.; southward to Townsend Hill its trend is N. 40° E.[1] In the angle a considerable exposure of the overlying Carboniferous rocks is preserved. Behind the mill on Annawan street the arkose rests directly upon the granite or is separated from it only by a thin course of coaly shale. The contact is well shown. Arkose layers, composed chiefly of angular quartz grains derived from the granite, alternate with coaly shale layers. Northward toward the railway tunnel under the next street, the alternation of arkose and coaly shale layers continues, the arkose changing to a gritty sandstone; the coaly slate then forms a considerable exposure, overlying the arkoses, and constituting the steep wall of the hillside as far as the railway track; strike N. 50° E., dip 40° W.; farther south, strike N. 30° E. Fern impressions occur in the shales. West of the railway track occurs a gritty sandstone.

TOWNSEND HILL.

Two and three-fourths miles southwest of the exposure in Fall River occurs the exposure on the west side of Townsend Hill. Granite forms the hillside down to the 100-foot contour. Below, where a small bench occurs, forming a northerly projection on the hillside, the arkose is exposed. The actual contact with the underlying granite is not seen, the stratigraphic interval being about 5 feet.

[1] The existing escarpment seems to me to be due to the deformation of the granite formation of the basin and the subsequent removal of the softer stratified beds. If the Carboniferous shore lay along this line, it was there but for a short time during the progressive overlapping of the accumulating basal sediment.—N. S. S.

TIVERTON.

The granite escarpment trends N. 30° E. as far as the western side of Pocasset Hill, changing thence to N. 13° E. as far as the exposures northeast of the railroad bridge. The lowest exposures of the Carboniferous series occur in the quarry on the hillside. Here the prevailing rock is arkose. The lowest part of this arkose, stratigraphically, occurs very near the granite. Nearer the lower end of the quarry blackish shale occurs. Tracing the exposures northward, a whitish, fine-grained, quartzitic rock, very much like the rock exposed west of East Greenwich, occurs between the Carboniferous rock and the granite, and is evidently pre-Carboniferous. Along the railroad tracks, overlying the grits, occur abundant exposures of conglomerate, composed chiefly of quartzose pebbles, some of them 8 inches long. No granite pebbles were seen. Coarse sandstones are interbedded. The abundance of quartzose pebbles and the absence of granite pebbles here is paralleled at Steep Brook. The more northern exposures along the railroad have a strike N.-S. and dip 30° W. At the quarry the strike becomes N. 35° E., the dip 40° W.

The next exposure of Carboniferous rocks occurs a mile and three-quarters farther south, east of the northern end of Nannaquacket Pond. At the northern end of the pond the granite appears at the shore. But a short distance farther south, on the hillside, the arkose is seen resting upon the granite. A little coaly shale is interbedded with the arkose. Strike N. 20° W., dip 45° W. Farther south the granite comes down to the roadside. It is evident that the contact line between the Carboniferous rocks and the granite must turn westward where Sin and Flesh Brook enters the pond. Granite occurs also along the northern side of Sin and Flesh Brook near the pond, and also directly north of the pond, on the north side of the road skirting the same. This would require a still farther westward trend of the shore line.

Returning to the arkose exposure, the granite comes down to the road near the fork of the way. North of the road, after passing the turn toward the east, the arkose occurs again high up on the hillside, but associated with considerable coaly shale. The strike here is N. 85° W., dip 65° to 70° S. If the observer crosses the road at its bend, he will find an excellent exposure in the open area on the hillside, southwest of the wooded summit. Here the

contact between the granite and the overlying Carboniferous rocks is again well shown. The clastic rocks consist of a series of interbedded arkoses and coaly shales, sometimes one, sometimes the other kind of rock forming the contact with the granite. The contact line is usually very distinct. The same strike of N. 85° W., dip 60° S., is shown. The arkose and granite contact can be followed as far as the creek entering Nannaquacket Pond from the east. From the pond southward it evidently takes a more southerly course, following the eastern side of the low land west of the granite hill, and then following the valley of a small brook as far as Tiverton Four Corners.

North of Nannaquacket Pond normal granite occurs, as already described. Still farther north a white fine-grained micaceous schist is exposed over a considerable area, until farther northward the granite appears again. The whitish micaceous schist may be followed eastward across the north-south road. It forms the southern end of the hill north of Sin and Flesh Brook and occurs along the northern branch of the stream. It also occurs south of the brook, the line of contact with the granite crossing south of the ice-house pond. West of this pond, along the road, the schist has been brecciated so as to resemble at first sight a conglomerate. In places this rock looks very much like a very fine-grained aplite made schistose by shearing. East of the ice house, between the branches of the brook and also south of the south branch, a greenish schist, often containing a dark-greenish hornblendic-looking mineral, is common. The granite north of this schist area not uncommonly also shows the effect of shearing and has a sort of gneissoid structure. The schist area has not been thoroughly studied. This will later, however, be desirable in order to learn whether the present eastern border of the Carboniferous area north of Nannaquacket Pond is due to the topography of the early Carboniferous sea bottom or is a result of subsequent sliding of the more northern pre-Carboniferous granite to the westward.

GOULD ISLAND.

The main mass of the island consists of a very fine-grained rock, varying in color. In some places it is white, with minute black specks, probably biotite; in others it is light bluish gray or dark blue; in still others it is gray, but contains many light-colored blotches. This rock has been extensively brecciated by a shearing action which took place in a direction

about N.-S., or a little west of north. In consequence of the brecciation the rock often has a decidedly conglomeratic appearance. Where shearing has taken place the pebble-like fragments usually remain light in color and the cementing material is darker. In other places the fragments are very dark in color and seem macroscopically to be full of hornblende and black mica. These dark fragments resemble closely the so-called dark or hornblendic schists of the Sin and Flesh Brook section, while the light-colored rocks resemble the lighter so-called quartzitic schists of that section. A pinkish aplite cuts the rock near the southeast end of Gould Island in the form of narrow dikes.

GRANITE AREA OF THE NORTHEAST END OF AQUIDNECK ISLAND.

Whitish granite occurs along the southern margin of Hummock Point, and reddish granite is found along the east shore farther north. A pinkish aplite cuts the same. Whitish granite forms a hill extending north of Hummock Point as far as the railroad. The granite is frequently sheared in a north-south direction, the result varying from a gneissoid granite to a black mica-schist. Half a mile north of the railroad another set of ridges begins, extending northward. It consists of whitish granite, sheared in a direction west of north, often N. 20° W. One result of the shearing is again a gneissoid structure, varying to a black mica-schist. Associated with the granite toward the middle and northward is the fine-grained quartzitic rock already described as occurring with the granite northeast of the railroad bridge at Tiverton, and also as occurring in the Sin and Flesh Brook exposures. Some of the Gould Island rock is also very similar in character to the whitish rock at the northeast end of Aquidneck Island, the whiter rock being probably identical in the two places. At Common Fence Point occurs a reddish granite, not gneissoid.

The rocks exposed from Gould Island to Common Fence Point are evidently pre-Carboniferous, and belong to the same series as the Sin and Flesh Brook exposures, and that northeast of the Tiverton railroad bridge on the hillside. The Carboniferous exposures on the hillside northeast of Tiverton are noteworthy, suggesting that the eastern border of the Carboniferous area extends southward toward the stone bridge. Possibly this

border passes southward from the stone bridge, rounds the granites and schists north of Nannaquacket Point, and then continues southward, east of the pond. In that case the pre-Carboniferous range of exposures between Gould Island and Common Fence Point must have been brought to their present position by means of a fault bringing up these rocks from below. At least there is no evidence that the Gould Island-Common Fence Point range of exposures formed an island in the Carboniferous seas.

This explanation makes it unnecessary to hypothesize any connection between the Common Fence Point range of granites and the Bristol Neck granite area above the water surface in Carboniferous times.

EASTERN BORDER OF THE CARBONIFEROUS BASIN SOUTH OF TIVERTON FOUR CORNERS.

Half a mile south of Tiverton Four Corners granite is exposed on the northwest side of the hill, south of the brook entering Nonquit Pond from the east. The granite continues to be exposed southward for a short distance, when greenish rock, having the appearance of a very fine-grained sandstone, occurs. Its schistosity is N. 40° E., dip 45° SE., and there is a probability that this should be taken as the strike and dip of the bedding. This rock is exposed along the apparent strike at a number of places on the northwest side of the hill. A quarter of a mile southeast, along the roadside, the granite is abundantly exposed. The granite has been sheared so as to present a pseudo-gneissoid structure with a northeasterly strike. The granite and the fine-grained rock are pre-Carboniferous. The eastern border of the Carboniferous area probably extends from Tiverton Four Corners east of Nonquit Pond and west of the granite hill southward.

The granite is well exposed along the southern end of the hill northeast of Tiverton Four Corners, almost east of the church north of Tiverton. On the east side of Borden Brook the granite has been considerably sheared in a direction about N. 30° E. The granite of this region contains in places abundant phenocrysts of feldspar from 1 to 2 inches in diameter, and these have been sheared to a lenticular form, producing a sort of augen-gneiss. Where the shearing was more marked the black mica increased in quantity. Extreme shearing reduced the granite in places to a biotitic schist, whose real character it is not possible to recognize in the case of every exposure. Gradations from one into the other can, however, be found.

The hill east and north of Pachet Brook also shows abundant granite exposures along the southern and eastern sides of the elevation. On the southeastern side it includes, in several places, large fragments of rock, having in some places the structure of a biotitic fine-grained schist of blackish color, in others that of a very fine-grained whitish rock, mottled, when broken across the schistosity, with blackish specks caused by biotite flakes. These included schist masses are distributed along a line N. 30° E. in an irregular manner. They present the same strike in their schistosity, and dip about 60° to 70° E. It would seem, therefore, that they once formed a connected series in this region. It would be interesting to learn whether these schists bear any close relation to the Little Compton shales farther south, but they probably preceded them. The granite near these schists is often porphyritic with large phenocrysts of feldspar. This is also true of the nearest exposure of granite east of the north branch of the brook. Farther eastward the granite is of the ordinary type. Southward, west of the south branch of the brook, at various points near the road, a whitish granite is exposed. Farther westward there is no exposure of any kind for almost half a mile, until the Little Compton shale outcrops are reached. The line of western outcrop of the granite must therefore pass somewhere between these regions in a southeasterly direction. It probably extends west of the road leading north from Little Compton; 1½ miles south of Little Compton post-office it is known to turn toward the southwest, reaching Sakonnet River, south of Churchs Cove, about a mile north of the breakwater. The granites from here south to the point are often coarsely porphyritic.

SANDSTONE SERIES BETWEEN WINDMILL HILL AND THE COVE NORTH OF BROWNS POINT.

South of the mouth of the outlet of Nonquit Pond coaly shales are exposed along the shore, bordering the same for about 700 feet. Then sandstone occurs on the west of the shales, showing fine cross bedding, made distinct by thin layers containing more carbonaceous material. The general strike is parallel to the shore, or N. 20° E., dip 45° to 65° W. Farther south an inward bend of the shore exposes the coaly shale again. These shales contain indistinct leaf impressions of unknown affinities, and traces of ferns can still be found. Farther south there is more sandstone, but here east of

the coaly shale, and dipping 45° E. If this indicates an anticline, it is evidently a sharp one, and the folding has been obscured in the shales by abundant cleavage in several directions. It is also a long fold, extending from the most northern shale exposure for at least half a mile southward. The sandstone, dipping east, at the north has a strike of about N. 5° E., following the shore for a considerable distance, and at the south end the strike changes to N. 30° E., the dip being 50° SE. Beyond this is a fault having the same trend of N. 30° E.

In some places the sandstone is very coarse and contains a great number of small pebbles. Toward the fault the sandstone is often very quartzitic, somewhat resembling the arkose along the shore, but the quartz grains are as a rule much smaller in size. South of the fault line the shore is bordered by sandstone, often coarse, or filled with small pebbles; less frequently it is decidedly conglomeratic, with much stretched pebbles. Just south of the fault a fine conglomerate bed was once overlain by black shale, small patches of which are still scattered over its surface, indicating a general southerly dip of about 20°. Farther south the strike is N. 70° W., dip 25° S., but there is also evidence of cross bedding, suggesting shallower water eastward. Near the most western extension of the shore a long plant stem is exposed for several feet in the coarse sandstone, but shearing makes it impossible to identify it. Small plant stems occur near by, resembling the Silver Spring plant stems. Farther south, at the western termination of the Almy Farm road to the shore, the coarse sandstone, containing numerous fine pebbles, shows a strike of N. 60° W., dip 20° SW., indicated by numerous patches of coaly shale, which cover its surface and which once were connected and formed a continuous layer.

Southward from this region the bedding is often difficult to follow for any considerable distance. Not infrequently the strike is nearly east-west, and the dip is then southerly, usually about 20°. But at many points along the shore there is bedding striking more nearly parallel to the shore and dipping westward, often very steeply. In some cases, especially where the dip is very steep, this west dip seems to be partly due to folding caused by pressure transverse to the trend of the border of the basin. Frequently, however, it is accompanied by distinct evidences of cross bedding. In such cases a steep westward dip not infrequently curves westward so as to reach

an almost horizontal position. At some localities a general study of the rock indicates that more or less horizontal beds were repeatedly attacked on the west side by waves. The westward-sloping cut-out margins of these beds were later covered by similar sand beds, which were themselves nearly horizontal. This whole series at present dips in a general way southward at an angle of about 20°. Toward the south the strike seems to be more nearly N. 60° E., dip 45° E., the dip decreasing rapidly southward until it becomes only about 10°. It is difficult to determine the real strike of the more southern shore outcrops.

North of the fault line mentioned above, the sandstone rarely contains pebbles over an inch long. Southward for some distance there are distinct conglomerate layers. The pebbles usually do not exceed 3 inches in length, although some beds show pebbles somewhat longer, considerably stretched. Granite pebbles are not infrequent, but are hardly recognizable on account of the extreme shearing.

A very coarse conglomerate, some of the pebbles a foot in length, occurs along the farm road west of the house on the west side of Windmill Hill. Many of these pebbles are composed of quartzite and are of much larger size than the pebbles in the exposures along the bank farther south. They occur between the 60-foot and 80-foot levels.

Nothing is known of the stratigraphic position of these rocks. The following remarks, however, may be pertinent. The present eastern margin of the Carboniferous basin, as a rule, shows arkose and coaly shales as the basal beds. Overlying these is sandstone, often with conglomerate layers. If the mass of coaly shale, sandstone, and mostly fine conglomerate so far described be conceded to represent the basal beds of the Carboniferous series in this region, then the very coarse conglomerate so abundantly exposed in the bed of the farm road on the west side of Windmill Hill may be considered as representing a higher horizon and as overlying at least the great mass of the sandstones.

If this view be correct, the coarse conglomerate on the west side of Windmill Hill could then be correlated with the coarse conglomerates exposed at High Hill Point, Fogland Point, the northwest side of Nonquit Pond, and thence northward.

COARSE CONGLOMERATE SERIES ALONG THE EAST SHORE OF SAKONNET RIVER.

HIGH HILL POINT.

Southeast of High Hill Point, near the western end of the beach, is an exposure of very coarse conglomerate, with pebbles often 15 inches long. An included sandstone layer shows the dip to be about 10° E. At the south end of High Hill Point the coarse conglomerate is again exposed. Near the east there is an included sandstone bed showing horizontal bedding. Farther west, and higher up the cliff, another interbedded sandstone layer shows a dip of 10° W. The same dip is shown at the north end of High Hill, although here the sandstone layer abuts against conglomerate on the east, and is itself cut off by conglomerate on the west, so abruptly as to make the real bedding at first sight uncertain. The conglomerate is exposed in a small indentation north of the hill, and continues along the bank northward for a short distance. Toward the west of the most northern exposure of the coarse conglomerate a fine conglomerate overlain by a little sandstone comes in, having a dip of 30° E., and this is underlain by coarse sandstone, which in certain layers is so full of very small pebbles, an inch and less in size, that the rock may be termed a fine conglomerate. Occasionally the rock contains coarser layers, with pebbles up to 1½ or 2 inches in length.

The great mass of the rock, however, is sandstone or the very fine conglomerate. It continues to be exposed northward for a quarter of a mile, the dip, however, soon diminishing to 10° E. The general strike of the rocks seems to be about N. 10° E. The sandstone is very similar to the sandstone bordering the shore southwest of Windmill Hill, southward toward Browns Point, and with this it is correlated. The overlying coarse conglomerate is correlated with the exposure on the west side of Windmill Hill, just west of the farm house.

FOGLAND POINT.

A short distance north of the southern end of the headland terminating in Fogland Point, the very coarse conglomerate with large pebbles is exposed, and from that place northward it borders the shore halfway to the point. The strike is about N. 10° E., dip 10° E., becoming a little less

to the northward. North of the conglomerate, almost as far as the point, the shore lies on a greenish shale, interbedded with a schistose rock which is evidently a sheared sandstone without pebbles. The strike of this rock is about N. 10° to 20° E., dip 10° E., and it certainly underlies the conglomerate. Its greenish color and shaly character resemble that of the rock underlying the coarse conglomerate at Eastons Point. At the southern end of the headland a similar greenish shale is exposed, also striking N 10° E., and dipping 10° E. This would make this exposure overlie the coarse conglomerate. If a fault be supposed to intervene, only a slight displacement would be necessary to bring up the lower shales to this position. This green shale beneath the conglomerate is believed to be stratigraphically related to the sandstone and fine conglomerate series below the conglomerate at High Hill Point.

EXPOSURES WEST OF NONQUIT POND.

A barrier beach connects the headland of Fogland Point with the mainland. East of the beach lies a broad hill, crossed by an east-west road. On the western side of the hill the road is crossed by a long set of very coarse conglomerate exposures, the strike of an interbedded sandstone being about north-south. This exposure lies not far west of the line of strike of the exposure on the west side of Windmill Hill, with which these various conglomerates are correlated.

A quarter of a mile south of Coreys Wharf a bluish-gray to black shale or fine-grained sandstone is exposed, some of the layers being very black and shaly. A short distance south of Coreys Wharf the rock is a bluish sandstone. No trustworthy strikes and dips could be followed for any distance; but these exposures are believed to underlie the coarse conglomerate. Lithologically they are somewhat similar to the more northern rocks exposed along the shore west of Windmill Hill.

The very coarse conglomerate is exposed at various points along the 80-foot hill west of the north end of Nonquit Pond. North of the east-west road one interbedded layer of sandstone shows a westward dip of 10°. The strike is probably about N. 10° E.

EXPOSURES BETWEEN TIVERTON FOUR CORNERS AND THE NORTHEAST SIDE OF NANNAQUACKET POND.

Northwest of Tiverton Four Corners a tract of meadow land and marsh runs toward the bay. North of this, a little east of north from the last exposure described, the coarse conglomerate is exposed in several places. The more northern exposure shows a strike of N. 32° E., dip 50° W. Eastward, on the western side of the hill, west of the road, are several exposures of coarse conglomerate not showing a marked strike or dip. The line of strike of the exposure described above, if extended, would reach a hill showing steep cliffs on the western face, where interbedded sandstones show successively, northward: strike N. 50° W., dip 60° W.; strike N. 75° W., dip nearly vertical, and strike N. 30° W., dip 70° W. Northward a small exposure shows a strike N. 5° E., dip about 70° W. A large steep exposure northward has the same northerly strike. The next has a strike N. 45° W., dip 60° W. Northeastward, nearer the road, are several exposures, the most western of which has a strike north-south, dip steep west. Then, after a rather long interval, in the southeast angle of the crossing of the Tiverton with the Sapowet Point road, the coarse conglomerate is exposed again with a strike of N. 70° W., dip 35° SW. The most westerly exposure north of the Sapowet Point road shows a strike also N. 65° W., dip 60° W. Nearer the crossroads the dip seems very low southwest. At an intermediate point northward the strike is N. 15° W., dip 30° W. No satisfactory bedding is shown by the exposures in the little creek which runs west about a quarter of a mile from the crossroads. In the valley of this brook, however, a little east of the line of outcrop of the conglomerate, occurs a sandstone and shale exposure, in places of a rather dark color, which may represent the sandstone series underlying the coarse conglomerate. Unfortunately, the exposure is not large enough to determine the matter.

North of this little stream, on the western side of the summit of the hill, a series of exposures continues northward. One of these shows a strike N. 40° E., dip steep, perhaps 60° W. (uncertain). The most northern exposure, on the north side of a circular embankment, shows strike N. 80° E., dip 85° N. Northeast of the private road, on the slope toward Nannaquacket Pond, an exposure has a strike N. 85° E., dip 75° N. After that the exposures continue to trend northward east of Nannaquacket Pond. Coarse conglomerate is exposed along the Tiverton road not far north of

the southern end of the pond; strike N. 85° W., dip 60° S. Northwest, near the end of a point projecting into Nannaquacket Pond, is dark, almost black, sandstone, which seems to strike N. 75° W., dip almost vertical. It may be sandstone belonging beneath the coarse conglomerate series. In that case a fault or sharp anticlinal fold must be imagined along its northeast side. At the bend of the road, nearly east, the conglomerate strikes N. 75° W., dip 70° S. Near the north end of the hill forming this exposure unsatisfactory exposures indicate a strike of N. 35° W., dip 70° E. North of a small stream a small hill occurs west of the road. Near its southern end coarse conglomerate is exposed. Northwest, at the shore, an interbedded sandstone layer shows strike N. 3° E., dip apparently 50° W. South of the creek and east of the road numerous bowlders of dark-blue to black sandstone, sometimes shaly, occur toward the northern end of a hill. The trend of the hill is N. 10° E. These sandstones are of the kind which underlie the coarse conglomerate series and which are found eastward in the series resting upon the granite associated with and over the arkoses.

The greatly varying strike and dip of the coarse conglomerate series here described may be partly due to cross bedding. In still larger measure, however, it is the result of the breaking up of the conglomerate series by a system of faults into numerous large masses or blocks, with frequent and variable tilting, but not enough to disguise the essential unity of the series. In general these blocks show a northward strike and westward dip. At Fogland and High Hill Points, however, there are low eastward dips showing a shallow syncline between this and Windmill Hill. Southward this syncline probably became strongly accentuated, giving rise to the steep eastward dips of the coarse conglomerates on the west side of Sakonnet River from Black Point to Smiths Beach.

On the west side of the neck west of Nannaquacket Pond, about two-thirds of its length from its north end, occur several exposures of grayish sandstone and of conglomerate with medium-sized pebbles, of which the stratigraphic position can not be determined.

LITTLE COMPTON SHALES.

From Browns Point to the south side of Pachet Brook southward, within half a mile of the road running north from Little Compton, thence westward and along the shore as far as the granite area, extends a series of slates and shales which evidently constitute a geological unit. The most

northern exposure of these shales along the shore is at Browns Point, along the northerly trend of the shore line. A second similar exposure occurs where the shore turns toward the southeast. The strike of the more northern exposure is N. 32° E., dip 45° E. The more southerly exposure has a strike N. 20° E., dip 45° E. The rock is of a greenish color, and has been cleaved like the rocks east of the brook.

The next exposure of the series occurs almost east of the mouth of the brook, a little south, near the 20-foot level on the hillside. A quarter of a mile northward exposures occur along a road leading eastward up the hill. From this point there is a succession of exposures extending northeastward up the hillside. This line of outcrops crosses the road at one of its more marked bends on the summit, continuing in the northeasterly direction along the hilltop and down the northeastern slope to a point a short distance north of the first road leading east.

The series evidently underlies the whole of the hill east of Browns Point. The ordinary appearance of the rock is that of a very fine-grained whitish quartzite traversed by cleavage planes, usually a fifth of an inch apart, along which black mica is abundantly developed. The result is a general stratified appearance of the rock, the strike of the cleavage being on the average N. 40° E., dip very steep, almost vertical. Behind the barn, east of the angle of the road mentioned above, the rock is fine grained, greenish, slightly banded with darker material. Southeast of this hill occurs another elevation, not marked upon the United States Geological Survey map, occupying the middle area of the quadrangle formed by the roads northwest of Little Compton. The whole of this hill is also underlain by the cleaved fine-grained whitish quartzitic rock. The exposures are most frequent on the western and southern slopes. The more northern outcrops on the western sides show a cleavage running about east-west; farther south and southeast it runs about N. 25° E. The rocks are here evidently much contorted and wrinkled. The stratification in places is clearly not in agreement with the cleavage. It is very desirable carefully to work out the real plane of bedding of this quartzitic rock and to determine its dip and strike. The shore exposures farther southwest, however, suggest that the general dip is southeasterly.

South of Browns Point is a cove. At the headland forming its southern extremity the rock is shaly. Exposures occur southward along the

shore at low tide. A third of a mile south of the cove, along the shore, the fissile green shale shows purplish coloring along certain beds, and in places there seem to be fine bands of a dolomitic limestone showing a pinkish coloring. The strike here is N. 8° E., dip 15° E. A quarter of a mile southward the strike is N. 20° E., dip 35° E. At Churchs Point the shales strike N. 15° E., dip 40° E. A third of a mile southeast, south of the mouth of a small stream, there is an exposure too massive to indicate the attitude of the beds. Farther south close observation shows a fine-grained rock cleaved very much like that of the two hills toward the north, first described; strike N. 30° E., dip 40° E. Massive rock occurs again a quarter of a mile south of the stream last mentioned, in a small indentation of the shore line; also at the projecting outline farther south, and at the next two similar projections of the shore. The strike is apparently N. 10° E., dip 60° to 70° E. North of the angle in Churchs Cove the rock has again a more whitish quartzitic appearance; strike N. 10° E., dip 25° E. A short distance south of the point where the shore line takes a southerly trend the greenish shale is again exposed. Certain layers are tinged with purple, and pinkish or light-red very thin dolomitic bands are again seen; strike N. 15° E., dip 15° E. The greenish shales continue to be exposed all along the shore as far as the granite area. Just north of the granite area they are again frequently tinged with purple and also show the very thin dolomitic bands. Their strike is N. 3° E., dip 20° E. The tingeing of purple with the thin banding of dolomitic material suggests that these shales are identical with the shales forming the western third of Newport Neck.

A distance of about 50 feet intervenes between the above-described shales and the next exposure of rock. This is a rather dark rock, containing abundant brecciated fragments of a dark-greenish stone, and apparently also fragments derived from a granitic mass. It strikes in a direction about N. 40° E., and evidently follows the northern line of the granite mass. It is believed to be a breccia formed during the faulting which brought the shales and the granite into juxtaposition here.

The green Little Compton shales are believed to be of pre-Carboniferous age. The granites on the south are also considered pre-Carboniferous. The granites may, however, be more recent than the Little Compton shales. In that case the shales near the contact would appear more massive and more like hornstone, resembling the Dumpling rock south of Jamestown on Conanicut.

CHAPTER VI.

AQUIDNECK, OR THE ISLAND OF RHODE ISLAND, WITH THE ISLANDS OF NEWPORT HARBOR.

ARKOSE AND PRE-CARBONIFEROUS ROCKS ON SACHUEST NECK.

ARKOSE.

At the promontory almost half a mile south of Flint Point, greenish shaly rocks are exposed along the immediate shore, but farther out the promontory is composed of arkose. Interbedded layers of coaly shale show that the arkose occurs in the form of a low anticline, whose axis pitches northward at a low angle and trends parallel to the general coast line, about N. 20° E. It is evidently a great block of grit which once lay above the level of the green shale series, but was dropped by faulting down to its present position in the green shale area.

Along the shore the green shales occur as far northward as a point a quarter of a mile south of Flint Point. Here they change from their former trend of N. 20° E., dip 60° W., to N. 45° E., dip 35° W. A short distance north the arkose series comes in with a similar strike and a nearly vertical or steep western dip. The strike changes rapidly to N.-S., dip 45° to 60° W., and continues as far as the quartz-veined promontory southeast of Flint Point. Between this and Flint Point interbedded coaly shales show that the arkose series dips about 70° W. West of the point the dip becomes almost vertical, then 70° to 60° E., then 75° E., 60° E., 35° E., and 80° E., the exposures of the arkose series terminating on the shore about 600 feet southwest of the point. A closer examination of the line of exposure between this more western point and Flint Point shows that the arkose is here several times closely folded, the western sides of the folds being sometimes a little overturned, in consequence of which there appears to be a fairly general steep eastward dip. Coaly shale layers are frequently interbedded with the arkoses, the latter, however, predominating. These coaly shale layers are very numerous elsewhere in the series,

and are frequently present on the west and southeast sides of Sachuest Neck. On these sides at least 300 feet of arkose material is exposed.

On the western side of Sachuest Neck the exposures begin not far from the beach. A coaly shale bed belonging in the arkose series lines the shore at its upper margin, against the hillside, for a long distance. Fern-leaf impressions and species of Annularia occur in this layer just northwest of some old farm buildings. The dip is about vertical or at times very steep eastward at the north end, but southward it is more regularly and decidedly west. Westward, near low-tide levels, the arkoses show a lower western dip, and this low westward dip becomes more marked and more general southward. At very low tide the arkose series is seen to change from its ordinary strike of N. 15° E. to N.-S., and then to N. 20° W. northward at one point near the northern end of these western exposures. These features probably indicate a secondary synclinal structure west of the neck. The westward dips continue as far as the point. Near the point the strike is about N. 23° E., dip 45° W. Along the east side of the point there is a well-marked fold whose axis trends N. 8° E. This can be followed northeastward along the shore, and 250 feet north from its most southern exposure the axis of the fold turns quite abruptly eastward, so as to trend N. 50° E. Then it changes again to a more northerly direction, showing synclinal structure on the northwest side, and on a larger scale on the southeast, the trend northward seeming to be N. 16° E. Not far from the most northeastern exposures of the arkose series a small fold is shown, its axis trending N. 8° E., its anticlinal nature being not at first sight very noticeable, owing to a slight overturn of the fold in part of the exposure. The most eastern arkose exposures show a strike about north-south; the dip is about 20° to 30° W. Along this most eastern exposure the arkose at low water shows on the east of the normal arkose a very granitic-looking rock in which the feldspar can be easily recognized. Farther up the beach, near high-water mark, the arkose shows at its base a mass of unquestioned coarse porphyritic granite, about 3 feet long, with phenocrysts of feldspar, like those at the Cormorant Rock, over a mile southward, and elsewhere. It can not be determined whether this is only an included bowlder or the upper part of the granitic mass which once furnished the material for the arkose. From the well-preserved feldspars in the granitic rock toward the sea, it is evident that if this lower rock be not itself granite the original

granite mass could not have been far away. It seems probably that the porphyritic granite near high-tide level may be a part of the original granite mass and not a bowlder derived from the same. The existence of this granite with large feldspar phenocrysts at Little Compton, and southeast of Almys Pond, south of Newport, as well as at the Cormorant Rock, makes such a supposition not impossible.

PRE-CARBONIFEROUS ROCKS.

The Island Rocks and other associated rocks off the northeast coast of Sachuest Neck are all composed of a greenish rock, varying between a slate and a shale, striking about N. 24° E. and dipping westward. The Island Rocks resemble very much the more quartzitic rock in the hill exposures east of Browns Point. The green shales are also exposed along the east shore of Sachuest Neck, from a point a quarter of a mile south of Flint Point to the arkose promontory a quarter of a mile farther south. Near its northern end the shale contains a little conglomerate, striking N. 43° E., dip 35° W. This changes soon to strike N. 33° E., dip 60° W., this strike and dip being maintained as far as the arkose promontory. At the north end of the cove, southwest of the promontory, the rocks strike N. 35° E., dip 35° W.; southward in the cove the strike changes to N. 40° E., then N. 45° E. toward the southern side of the cove, changing to N. 30° E., dip 60° W., near the south end of the cove. The more southern exposures along the cove show considerable conglomerate with angular fragments, and from this point southward most of the rock is conglomeratic. A whitish sandy band makes its appearance in the conglomeratic greenish rock. It is similar to some of the more quartzitic rock in the Little Compton shale series on the hill east of Browns Point. This can be followed for a considerable distance, having strike N. 30° E., dip 60° W. at the north end, becoming steeper southward. The shore here makes a convex curve. Toward the southern end of this the strike is still N. 33° E., dip 80° W., but immediately beyond the strike becomes N. 58° E., dip 70° E., changing southward to N. 53° E., dip 60° E., and then, at another convex curve in the shore line, to N. 35° E., dip 45° E. Southward there is a small promontory halfway between the arkose promontory and Sachuest Point. The strike here is N. 63° E., dip 60° E. West of the cove formed by this promontory the strike is N. 22° E., dip 80° E., becoming N. 30° E., dip

80° E., at the line of faulting separating this rock from the arkose series.[1] A short distance east of this fault line the rock contains a diabase dike.

It will be noticed that about halfway between the southern termination of the greenish conglomeratic rock and the arkose promontory the dip changes from steep east to steep west. North of the point the exposures seem to be successively lower. Southward toward the fault line apparently higher horizons are reached. Close observation, however, shows no signs of a fold there, where the steep dips change direction. A strong flexure in the rock previous to the faulting which exists farther westward seems to be the explanation, the flexure being of such a character that at a certain point the conglomeratic strata are nearly vertical. North of this point they dip westward; south of this point, eastward.

Exposures of the greenish conglomerate also occur on the hillside toward the southern part of the line of shore exposures. A line connecting the extreme shore exposures west and south would trend N. 22° E., and would pass just west of the most western of the hill exposures.

The position of the conglomerate with reference to the greenish shales is uncertain, but after detailed work on this question it was supposed to overlie the same, owing to the westward dip of the series northward toward the Island Rocks.

While the shales have the ordinary clastic appearance the conglomeratic beds present certain peculiar features. In the first place, the pebbles are usually decidedly angular in appearance, presenting, commonly, the aspect of fragments in a breccia. In the second place, there seems to be no marked tendency to arrange the fragments in layers according to size, as is commonly the case when fragments are transported by water action. In the third place, a large part of the fragmental material is lighter or darker in color than the cementing material when seen on the weathered surface of the rock. When broken, however, this distinctness to a great extent disappears, and the whole mass looks greenish, varying chiefly in fineness of grain. This is a feature more commonly observed in breccias than in genuine conglomerates. In the fourth place, the variety of material occurring in the form of fragments varies sufficiently to include four or five types. Some of these fragments seem to be certainly from some clastic rock. Others may be of igneous

[1] Prof. T. Nelson Dale raises the very pertinent question whether the facts may not be explained by assuming an unconformity, since Carboniferous arkose would probably rest in an unconformable manner upon Cambrian shale.

origin, but they do not resemble any known rock in the Carboniferous basin. Fragments of a reddish rock, often resembling jasper, occur here and there. In the fifth place, the absence of granite in the form of pebbles is very noticeable.

In several of these particulars the greenish Sachuest conglomeratic rock resembles the more northern exposures of the Dumpling rock on the eastern shore of Conanicut, south of Jamestown. There seems to be no question of the pre-Carboniferous character of the greenish rock, both shale and conglomerate. The absence of all granite fragments from the green series suggests that the granite is intrusive and therefore of later origin. The nearest granite exposures of any size are now at Cormorant Rock, but the exposure just beneath the arkose series suggests that it once reached as far as Sachuest Neck. The arkose series probably once rested upon the green series, a relation now obscured by faulting. It derived its materials, at least the coarser part, from the granite, which is therefore pre-Carboniferous. The grit is Carboniferous, as is shown by the interbedded coaly shale layers containing fossils. The interbedding of coaly fossiliferous shales with the grit seems to be characteristic of exposures along the eastern margin of the Narragansett Basin, several such occurrences being known at Steep Brook, Fall River, and Tiverton. The relative age of this eastern arkose as compared with that of the Aquidneck shale series can not be determined at present.

EASTERN SHORE OF AQUIDNECK ISLAND AS FAR SOUTH AS THE SECOND COVE NORTHWEST OF BLACK POINT.

The most northern exposure of Carboniferous rock on Aquidneck Island on the east shore occurs southwest of the cove, near the eastern base of Butts Hill. Coaly shale and sandstone are interbedded, being several times repeated southward for half a mile, as far as the wharf east of Portsmouth village. North of the wharf a short distance there is evidence of a low anticline, pitching southward, the dip being low on both sides. The exposures at the wharf and southward belong to the western side of this anticline, and therefore all dip westward. At the wharf there is sandstone on the north side, showing a cleavage dipping 60° W. Overlying the sandstone on the south side is a thin layer of conglomerate dipping about 10° E. But south along the shore exposures of conglomerate and dark coaly shales strike N. 3° E., dip 45° W. Southward sandstone

borders the shore, interbedded with a few coaly shale layers and a few thin conglomerate beds with small pebbles and flakes of carbonaceous shale; strike N.-S., dip 20° W. Yet farther south gray sandstone is abundant. Interbedded with this, south of a small stream, a third of a mile from the wharf, is black coaly shale; strike N.-S., dip 30° W.

Half a mile south of the wharf the coaly shale contains impressions of fern leaves; strike N. 3° E., dip 40° W. Southward occurs sandstone, overlain by several feet of fine conglomerate, the pebbles not exceeding 1 inch in length; dip 30° W. From the wharf southward rocks continually higher in the series are exposed, but owing to the fact that the strike is almost parallel to the shore, only a small thickness of strata is traversed.

From this fine conglomerate exposure southward the strike seems to be a little east of south, while the shore line curves inward in such a way as to expose, a third of a mile southward, gray sandstone in the form of large loose blocks. Then, two-fifths of a mile southward, large blocks of coaly shale occur, representing the highest rocks so far described. A third of a mile southward the gray sandstone seems to be repeated, descending in the series; strike N. 7° W., dip 10° W.; and only a short distance beyond, southward, the almost horizontal sandstone contains thin conglomerate layers with pebbles up to 1 inch in length. The more southerly of these exposures dip 10° W. The thin conglomerate layers continue to occur in the sandstone southward, and at several places they contain the fragments or flakes of coaly shales noted above.

In the Glen almost half a mile of exposure is seen. The rock is evidently the shale series, very much blacker and more coaly than the corresponding rocks on the west side of the island. East, toward the bay, about 25 feet above the water level, a Cordaites leaf was found in the shale. About 40 feet above the water level there is sandstone interbedded. A comparison of the Glen section with the shore exposures from McCurrys Point southward beyond Sandy Point shows that the shore exposures also belong to the shale series. As far as can be determined the shale series at the Glen dips low, 5° or 10° E. It certainly is nearly horizontal

Between the Glen and the beach of Sandy Point there is exposed sandstone sheared into a shaly rock, the shearing planes dipping east of south. No bedding could be recognized. South of the beach of Sandy

Point coaly shale comes in again. A quarter of a mile southward this has evidently been violently squeezed in an east-west direction.

South of McCurrys Point a small stream entering the bay from the west exposes from the shore to a considerable distance up the hill westward nothing but bluish-black shale of the type found so abundant on the western side of the island over the coal regions. These bluish-black shales evidently overlie the coaly shales, sandstones, and fine conglomerates so far described, and a small fault has probably thrown them a little eastward near the point. The cleavage obscures the stratification. The cleavage dips 15° to 20° W., and there seems to be a southward dip of perhaps no more than 5°. Southward the shale becomes blacker and more coaly and seems to be nearly horizontal. A quarter of a mile north of the mouth of the creek traversing the Glen it contains impressions of fern leaves. The coaly shale continues as far as the Glen.

A mile south of Sandy Point, or a little over half a mile from the southern extremity of the beach, dark-gray sandstone makes its appearance again. Over it occurs, southward, coaly shale, apparently dipping eastward, but this dip is of little moment, since southward there is abundant evidence of violent crumpling and folding of the rock by a force acting in an east-west direction. Southward more sandstone is seen sheared into a shale.

The absence of clear indications of the bedding at this locality and as far northward as McCurrys Point, and the violent crumpling at the last-described locality as well as south of Sandy Point, afford serious difficulties in attempting to determine the stratigraphic position of the coarse conglomerates in the southeastern part of Aquidneck.

The great Aquidneck shale series exposed at the Glen and along the shore is believed, however, to be overlain north of Black Point by the coaly Sakonnet sandstone with fine conglomerate, representing a section of much smaller thickness, 110 feet being exposed at the point, and this in turn is overlain by the coarse Purgatory conglomerate, whose maximum thickness as exposed along the shore apparently does not exceed 380 feet.

COARSE CONGLOMERATES AND UNDERLYING SANDSTONE SERIES FROM BLACK POINT TO THE NORTH END OF SMITHS BEACH.

About a quarter of a mile northwest of Black Point is a second promontory. In a cove immediately toward the west of the latter is bluish sand-

stone. A thin conglomerate layer with small pebbles shows a strike of N. 53° E., dip at first lower, then 30° SE. Eastward along the strike the sandstone becomes decidedly darker and more carbonaceous, the strike changing to N. 35° E. On the east side of the promontory the strike is N. 32° E., dip 45° SE. The dark carbonaceous sandstone series is continued on the east side of the promontory along the northern side of the cove north of Black Point. About 110 feet of the sandstone series are exposed. The lower 90 feet consist of the carbonaceous sandstones already described, with which are intercalated thin conglomerate beds with pebbles not exceeding 1 inch in size. Then occurs a layer of coaly shale 1 foot thick, above which are 7 feet more of the dark sandstone. Above are 8 feet of conglomerate with small pebbles, and, finally, 4 feet of the dark sandstone. On the north side of the cove north of Black Point the strike is N. 68° E., dip about 45° SE. Southward there is no exposure until the middle of the cove is reached, when the very coarse conglomerate comes to view.

The general strike of this conglomerate is about N. 22° E. At the northern end of the shore exposures, however, there is marked variation in strike. Near the middle of the cove the conglomerate includes a sandstone layer apparently striking N. 3° E., dip 80° E. Nearer the south end of the cove the strike is N. 48° E., dip about 60° E. South of Black Point the strike is N. 28° E., dip 60° E., the strike becoming about N. 22° E. farther south.

Notwithstanding this irregularity in the strike of the sandstone and conglomerate series, and especially the discordance between the average strike of the two series, the sandstone is believed to underlie the coarse conglomerate, the dips certainly favoring this view.

That part of the exposure from Black Point two-thirds of a mile southward is serviceable in estimating the thickness of the conglomerate series. About 380 feet of the coarse conglomerate series are exposed. The lowest part of the section is found near the northern end of the line of exposures. The upper beds are exposed along the shore, farther south. Beginning with the lowest part of the section, four beds of conglomerate may be distinguished, 19, 20, 11, and 32 feet thick. Above these lie 35 feet of sandstone, separated by a thin conglomerate layer from 29 feet more of sandstone; next, a thin black shale layer, then 23 feet of conglomerate,

at the top including fragments of coaly shale, followed by a 4-foot layer of conglomerate, also including fragments of coaly shale at the top. Above the conglomerate are 2 feet of coaly shale, 12 feet of conglomerate, 6 feet of coaly sandstone, 15 feet of grayish-black sandstone, 5 feet of grayish sandstone, 2 feet of black coaly shale, 14 feet of dark-gray sandstone, two layers of conglomerate 15 and 7 feet thick, 13 feet of sandstone, and, at the top of the section, three layers of conglomerate, 33, 23, and 27 feet thick.

A generalized statement of the chief characteristics of this section would be 82 feet of coarse conglomerate at the base, followed by 99 feet of sandstone, 41 feet of coarse conglomerate, 42 feet of sandstone, and 118 feet of conglomerate. The thickness of the great interbedded sandstone layers should be especially emphasized when the attempt is made to determine the relative horizon of isolated small sandstone and coarse conglomerate outcrops.

Along the line of outcrop described above, the dip varies, southward, from 60° E. to 45° and 40° E., becoming again 60° E. toward the southern end of the section described. Southward along the shore, at a promontory a mile south of Black Point, the dip increases to 80° E. The steep eastward dip continues southward, becoming 80° W. at Taggarts Ferry Cove, but returning to 75° E. again on the south side of the cove.

The very coarse conglomerate borders the eastern shore of Aquidneck Island as far southward as the north end of Smiths Beach, except in the cove two-fifths of a mile north of Woods Castle, known as Taggarts Ferry, where rocks occur varying between coaly sandstone and coaly shale.

On the shore west of the southern end of the cove, and along the creek south of these exposures, dark carbonaceous shale and sandstone are exposed for 30 or 40 feet. The shale series is believed to merge gradually upward into this peculiar coaly, carbonaceous shale and sandstone. Eastward along the shore overlying these land exposures is more sandy rock of the same character. Overlying this is found a coarser sandstone, overlain in turn by carbonaceous shaly rock, the dip varying from vertical to 85° W. Then comes, eastward, a coarser sandstone, with small pebbles, dipping 80° W. Toward the north, along the shore, a sudden twist causes the contact between this rock and the overlying carbonaceous shale to dip due east. Farther east, coarser sandstone, with fine conglomerate overlying it,

dips more steeply, 55° E Overlying this, conglomerate with medium-sized pebbles dips 70° to 80° E. Then comes a comparatively thin layer of coaly sandstone and a conglomerate with pebbles of medium size, both dipping 80° E. Then a considerable thickness of dark-gray, more carbonaceous shaly rock is exposed, and an equally thick bed, perhaps 40 feet, of rather coarse conglomerate, dipping 80° E. Overlying this occurs carbonaceous sandstone, with coarse conglomerate farther east; dip vertical or 80° E. along the promontory which they form at the north end of the cove; but farther north, along the shore, the same beds dip 80° W. This same dip, varying to vertical, is shown for some distance northward, until the beds gradually incline more and more eastward, as already noted. South of the cove the dip is 75° E. It is evident that the same beds of coarse conglomerate, with the underlying sandstone series, have been folded in such a way as to dip more steeply in coming southward along the strike toward Taggarts Ferry; at the ferry there is a slight overturn, the dip being 80° to 70° W., and immediately south of the ferry the dip returns to 75° E. with sufficient suddenness to denote a stronger flexure at the southern end of the cove

The Sakonnet sandstones in the cove and westward correspond stratigraphically to the sandstone north of Black Point.

From the cove southward to Woods Castle we pass from lower to higher rocks in the conglomerate series. The dip is steeply eastward—usually about 70° E. At Woods Castle a bed of coaly shale occurs, overlying that part of the conglomerate series forming the shore. It contains abundant fern remains. Eastward, after an interval of perhaps 30 feet, probably also underlain by shaly rock, the great isolated mass forming the conspicuous feature of this coast line is exposed. It is composed, at least on the west side, chiefly of coarse sandstone. The stratigraphy was not carefully followed, but the coaly shale bed seems to correspond to a more sandy, coaly shale exposed about a quarter of a mile north of the cove at Taggarts Ferry, and the sandstone overlying it replaces a coarse conglomerate. In other words, the fern locality at Woods Castle occurs well within the coarse conglomerate series, and not overlying the same. Southward, toward Smiths Cove, the dip is less steep, becoming, near the southern end, as low as 50° or even 45° E.

COARSE CONGLOMERATES AND UNDERLYING ROCKS ON THE NECK AT EASTONS POINT.

On the eastern side of the neck, at the west end of Sachuest Beach, the very coarse conglomerate series is well exposed along the shore for a length of almost half a mile, terminating southward in a long narrow promontory projecting into the sea. The strike of this conglomerate is about N. 20° E., dip 60° E., southward becoming only 45° E. Westward, beneath the conglomerate is greenish sandstone, often shaly. Interbedded with this is conglomerate, but not equaling the sandstone in quantity, and the pebbles are also much smaller than those in the very coarse conglomerate. The dip is still 45° E. Southwestward along the shore, still lower rocks are exposed—greenish shaly sandstone and shale, with conglomerate of rather small pebbles. The dip is 45° E., and the strike is still N. 20° E. Thence to Eastons Point there is a series of underlying greenish shaly sandstone and fissile shales, having an eastward dip. So far the exposures beneath the coarse conglomerate are so little divergent from the strike of the shore line that the section as far as the point does not represent any great thickness. Going northwestward from the point, we meet still lower rocks. At first greenish shaly rock continues the descending section, containing a little conglomerate a short distance west of the point. At one point west of the southern end of the neck ripple marks are seen in the shales. Nine hundred feet northwest from the point intercalated sandstones indicate a local increase of dip to 70° E., and then toward the axis the dip is lower eastward. The axis of the anticlinal fold is about a third of a mile northwest of Eastons Point. The dip on both sides is low. The pitch of the fold is about 10° S.

West of the anticline the dip is at first low W, 20°. This continues for some time until, about half a mile from the point, the dip increases to 45° W., the strike being still N. 13° E. Here are intercalated gray sandstone and conglomerate composed of small pebbles corresponding to the conglomerate just west of Eastons Point. Farther northwest the conglomerate layers become rather frequent, the dip being 45° W.; and this continues for some distance along the shore. The pebbles are only of medium size. Locally the dip becomes steeper west, at one point 80° W., but it soon returns to very low west, and then 45° W. again; near this point the very coarse conglomerate makes its appearance once more, about three-fifths of a mile

from Eastons Point, and a fifth of a mile southeast of the first exposures east of Eastons Beach. Northwestward the coarse conglomerate continues, with interbedded sandstone and a little carbonaceous shale. The dip decreases from 45° W. to 15° W. Westward along the shore the very coarse conglomerate with interbedded sandstone continues, the most western exposures becoming nearly horizontal, dipping at a low angle eastward, from 5° to 10° perhaps. At the extreme western end of the exposures the conglomerate shows an interbedded layer of dark carbonaceous sandstone, so disjointed by small faults along joints as to obscure at first sight the evidences of its former continuity. This layer, when reconstructed, indicates an eastward dip of 10° to 15°.

Comparing the two sides of the anticlinal fold, the western side is seen to have a lower dip. This feature is especially well shown near the extreme ends of the shore exposures, the dip at the Purgatory rocks being at least 60° E., while on the west side the dips for a long distance along the shore are low west, and then east, being in places practically horizontal. The shales on the western side of the fold are perhaps a little more carbonaceous, but in general the rocks show only a dark-gray color. In comparison with this the shale and sandstone series at Taggarts Ferry are very much darker, often black, and show a similar intercalation of medium-sized conglomerates just below the coarse conglomerate series. Near Black Point the series contains chiefly sandstone, which, although carbonaceous, is not so dark as the Taggarts Ferry exposure. Moreover, the change from fine conglomerate to very coarse conglomerate seems to be here more sudden.

PARADISE COARSE CONGLOMERATES.

PARADISE ROCKS.

The continuous exposures of the coarse conglomerates forming the eastern side of Eastons Point terminate northward at Sachuest Beach. The same series farther northward forms the Paradise Rocks. The lower beds of the conglomerate series are exposed a third of a mile north of the beach, west of the road, near a stream. They are chiefly sandstone, with a few conglomerate layers; strike N. 12° E., dip 70° E. Farther east, just west of the road, there are, almost in situ, very large conglomerate bowlders, with large pebbles, forming the base of the coarse conglomerates.

The sandstone beneath the conglomerates is again exposed five-sixths of a mile north of the beach, an eighth of a mile east of the road, north of a farmhouse. Here it is a bluish sandstone and dips about 40° E. The basal conglomerate not far eastward dips 60° E.

Almost the entire thickness of the coarse conglomerates exposed at the western Paradise Rocks belongs unquestionably to a single eastward-dipping series, combining northward to form the high ridge which is the conspicuous element of the landscape. At the more southern exposures west of the reservoir the conglomerate beds form a series of parallel ridges in the fields; strike N. 18° E., dip east. Northward, the second field containing exposures shows a dip of 60° E. in one of the middle ridges; this dip is better shown southeast of a house. The most eastern ridge, forming a steep cliff bordering the reservoir, has coarse conglomerate dipping 40° to 45° E. Passing northward out of the grounds immediately surrounding the Belmont House, the more western conglomerates form the southern end of the high conglomerate ridge, to which reference has already been made, dipping 50° E. on the west side and 60° E. on the east side, while the continuation of the conglomerate bed, bordering the reservoir, still dips 45° E. Farther north the bluish sandstone beneath the conglomerate series, already described, dips 40° E. The most western conglomerate exposures dip 60° E. Farther up the conglomerate ridge the dip becomes 80° E., diminishing on the east side to about 40° E. on the northward continuation of the conglomerate which farther southward borders the reservoir. Northward, at the quarry on the west side of the main ridge, the dip has diminished to 45° or 50° E., and as the strike swings eastward so as to become N. 30° E., the dip on the eastern side diminishes for a long distance to 30° E.

These exposures, with easily recognized eastward dip, terminate at an east-west field wall about a third of a mile south of the east-west road bordering the Paradise tract on the north side. East of the last exposure with marked eastward dip, and east of its line of strike, the exposure north of the fence shows an almost vertical dip, or 80° W. Eastward, in the field, a dip of 50° E. was noticed. A short distance to the southeast of these exposures, and east of their line of strike, the second and more eastern ridge of the Paradise Rocks begins. At its north end the dip is 70° to 80° E. This continues southward, as well as can be deter-

mined, notwithstanding evidence of some degree of folding. A subsidiary ridge west of the main line of outcrop shows almost vertical dips—80° E. on the east side, 80° W. on the west side—owing to a moderate divergence of the bedding planes of the two extreme layers. Southeastward the main line of outcrop begins again, with a dip of 85° W., and this nearly vertical dip is maintained for some distance south, becoming 70° W. at the most southern exposure, between the middle and western streams entering the reservoir.

A very important point should here be noted. While the mass of conglomerates forming the western and higher eastward-dipping Paradise Ridge is of considerable thickness, that forming the lower and practically vertical-dipping eastern ridge is only one-third or one-fourth as thick. So that, although a synclinal structure might be imagined between these two ridges, there is not as much conglomerate exposed on the east side of the supposed syncline as would be expected in the case of such a structure. Another equally important point is this: A continuation of the line of strike of the more eastern Paradise Ridge would reach a solitary coarse conglomerate exposure at the west end of Sachuest Beach, with strike N. 14° E., which has a dip of 40° E., but in order to agree with the synclinal structure demanded northward its dip ought to be west. Less important, because the exposures are not equally satisfactory, is the vertical dip shown by the exposure east of the north end of the continuous eastward-dipping line of exposures already described, where the dip is 50° E. The dip of the more eastern exposure should be westward to agree with synclinal structure in this region. The second, more eastern, ridge shows in places evidences of local folding.

In view of all the facts observed it seems reasonable to suppose that the Paradise ridges form a great eastward-dipping series of conglomerates on the western side of a syncline. The eastern of the two ridges dips eastward only at the southern end. North of the reservoir the conglomerate beds of this eastern ridge are affected by a local flexure traversing the series a little diagonally, which has bent these beds downward and moderately overturned them northward, so that the almost vertical but somewhat westward dip of the eastern ridge along its southern end is changed to an almost vertical but slightly eastward dip near its northern end, the dip of 50° E. in the field a considerable distance north of the second ridge, and

another of 40° E. on Sachuest Beach, south of the ridge, remaining to show the real structure of the series of which this eastern ridge forms a part.

At the north end of the western or principal ridge the lower eastward dips show that the syncline is more shallow northward. The low dips seem to continue northward, since the remaining conglomerate exposures as far as the east-west road fail to bring up on end the interbedded sandstones, and so their dip can not be determined. North of the road, however, in a field a fifth of a mile west of the road corners, conglomerate is exposed with a strike N. 30° E., dip 20° E., lower eastward. North of the road corners above mentioned blue sandstone with a little conglomerate dips low eastward, and seems to pitch southward. A sixth of a mile southward, west of the angle of the road, similar sandstone is exposed in a field.

HANGING ROCKS.

The Hanging Rocks, along the western side of Gardners Pond, form the southern end of another great ridge of coarse conglomerate. The strike of the conglomerate in the ridge is N. 16° E., dip 70° W., in some places almost vertical. Overlying it on the western side, northward, is a bluish, in places shaly, sandstone. This Hanging Rock ridge of conglomerate is about half a mile long. It seems to form the eastern side of a great southward-pitching syncline, of which the Paradise Rocks form the western side. Seen from one of the great trap ridges in the central area of this synclinal district, the topography favors such an interpretation of the series. Immediately east of Hanging Rock, north of the bend at which the road skirting it turns eastward, a low ridge of conglomerate is found, west of the brook. Its dip seems to be steep eastward, nearly vertical. Other exposures are found farther northward, west of the brook. East of the brook is another low conglomerate ridge extending southward into Gardners Pond and forming the eastern border of the narrow division of the pond into which the brook empties. The strike of the main exposure here on the west side is N. 16° E., dip from 80° W. to vertical. The fact that this exposure lies east of the line of strike of the exposures farther north, on the west side of the brook, which sometimes show eastward dips, should be noted. Along the eastern side of this promontory, near its southern end, the dip is about 60° E. This eastward dip continues to be shown by the continuation of the eastern side of this line of exposure northward, being 40° E. in the fields north of the road, the strike being N. 20° E.

East of the strike of this line of outcrops, at its northern end, west of a farmhouse, is another exposure of conglomerate striking N. 10° E., but dipping 80° E., and insignificant exposures are found southward from this last exposure.

If now the series of exposures east of the main Hanging Rock ridge be taken, and their dips be compared, it will be seen that there is a succession of steep, practically vertical, and of less inclined, eastward dips. This might at first sight be taken as evidence of a series of anticlines and synclines. But the ridge occurring immediately east of the brook which empties southward into the pond, changes from a steep, practically vertical dip near its southern end to a lower eastward dip on going northward, and also to a lower eastward dip on going southeast to the edge of the promontory on the pond. East of the northeast end of this ridge east of the brook the steep eastward, nearly vertical dip comes in again. It is believed that these conglomerates are not folded in anticlines and synclines, but that all form parts of a steeply west-dipping series affected by flexures varying as regards the dip along the strikes of the same beds, and apparently also varying in this regard in closely contiguous beds. This is a condition of things not infrequently seen when a general synclinal structure has been brought about in a series of harder rock separated by layers of softer material, which permit of more or less sliding. Structures of this kind may be seen on a smaller scale in connection with the folding at the north end of Sachuest Neck.[1]

The Hanging Rocks and more eastern exposures are believed to be the eastern side of a great syncline, of which the Paradise Rocks form the western side. The folding of the Easton Point anticline on the west side of this syncline is quite regular, and hence the eastern side of this syncline, which forms the western side of the Paradise-Hanging Rock syncline, presents quite regularly only the eastward dips, except along the eastern ridge, where very steep westward dips occur in places, as described. The anticline on the eastern side of the Paradise-Hanging Rock syncline is evidently the result of stronger folding, the dips from Smiths Beach to Taggarts Ferry being often 70° E., and at the ferry vertical or 80° W.

[1] Dale, Crosby, and Barton regard the structure of the Hanging Rocks district as an anticline. The conglomerate east of the Hanging Rocks dips east, while the Hanging Rocks dip west. This interpretation would demand the assumption that but a small part of the conglomerate on the western side of the anticline is actually exposed.

On the west side of the Woods Castle-Black Point anticline the series in the Hanging Rocks Valley is evidently somewhat overturned in places, although the chief ridge, that of the Hanging Rocks, dips 80° W. The result of the more accentuated folding, as indicated by the steeper dips, is a violent contortion of the rocks, shown by the local rapid variation of dip, due to local folding subsidiary to the more general synclinal folding which determined the great structural features of the Carboniferous area along the Hanging Rock Valley and westward. This syncline is believed to pitch strongly southward.

The most northern outcrops of coarse conglomerate occur a little over a mile from both Black Point and Taggarts Ferry, about three-quarters of a mile west of the Sakonnet River, along the west and east sides of the road. Here the strike is N. 3° E., dip 45° W., on the east side of the road southward, changing to strike N. 15° E., dip 40° E., on the west side of the road near the middle exposure, and dipping the same amount east at a continuation of the middle exposure northward on the east side of the road. This seems to represent the northern end of the syncline in the coarse conglomerate bed, and lies about 60 to 80 feet above sea level. Southward the base of the syncline pitches far beneath sea level.

PRE-CARBONIFEROUS AREA.

Between the eastern ridge of the Paradise conglomerates and the Hanging Rock ridge of conglomerate lies an area of igneous rock and of quartzite-schists which seems to be pre-Carboniferous. The most southwestern exposure of the hornblendic rock, possibly at the time of its injection a coarse diabase, is found along the southern embankment of the reservoir, at an angle near its middle line. The next exposure occurs at the northern end of the reservoir, between the middle and the eastern creeks entering the reservoir from that side. It there forms a ridge which can be traced northward for about half a mile, and is evidently in line with the exposure south of the reservoir. Bordering the east side of the reservoir is another, much loftier and broader range of the igneous rock, almost half a mile long. East of this lies a somewhat narrower ridge, at one point broken down and permitting the formation of a glen between the main range of igneous rocks westward and another high ridge lying to the eastward. This eastern ridge lies directly west of the Hanging Rock coarse conglomerate with its overlying bluish sandstone and more greenish shaly variety.

The igneous rock has evidently penetrated a great mass of quartzitic schists similar to those found west of East Greenwich, north of Tiverton, south of Common Fence Point, and elsewhere, and to a somewhat less degree like the quartzitic schists or shales east of Browns Point. These schists may be found well exposed in the area between the two main ranges of the igneous rock east of the pond and on the promontory between the middle and east creeks north of the reservoir. They were formerly also well exposed on an island in the southeastern corner, now covered by the reservoir. They occur also as fragments inclosed in the larger ridges of the igneous rock and in the smaller exposures of the same material. Curiously the strike and dip of the included fragments and of the larger masses of the quartzitic schist penetrated by the trap dikes are so constant that a general strike of N. 20° E. and a dip of 50° to 60°, sometimes 70°, W. will sufficiently explain their general relations to one another. On the promontory of trap rock north of the pond, however, it may be seen that this strike is chiefly the direction of the plane of schistosity, the bedding being apparently, at least in places, at variance with the same.

The igneous rock above referred to as cutting the pre-Carboniferous whitish quartzitic rocks in the Paradise-Hanging Rock region shows, even macroscopically, the presence of a crystalline structure. The rock is composed chiefly of plagioclase and hornblende, both in a very advanced state of decomposition. This combination would place the rock under the heading of diorite, and here it is placed by Mr. George P. Merrill, who first made a microscopical examination of these dike rocks. He makes, however, the qualification that "it is, of course, possible that this hornblende may itself be secondary and that the perfectly fresh rock would show augite; but this does not seem probable." If hornblende replaced original augite, the trap rock would then be an altered diabase.

With this determination of the igneous character of the trap rocks of the Paradise-Hanging Rock region in hand, Professors Crosby and Barton[1] were the first to make a careful study of these dikes, and they state that in no instance did they "discover the slightest indication of a passage from the dike rock to the [quartzitic] slate, but the two are always separated by a perfectly sharp and definite line."

The trap occurs in parallel ridges running in the same direction as the

[1] Proc. Boston Soc. Nat. Hist., Vol. XXIII, 1886, p. 325 et seq.

coarse conglomerate ridges. The largest of these are on the eastern side of the region here described. The great ridge west of the Hanging Rock ridge is composed almost entirely of trap, but shows toward the north, on its eastern face, toward the upper portion of the ridge, a number of long inclusions of the quartzitic slate which it in general intersects. This quartzitic rock is also shown on the western side of the same trap ridge, near its highest elevation; it also is exposed on the eastern side of the next ridge westward, and probably once occupied the valley separating the two ridges. This western ridge is also composed almost entirely of trap rock, the dike rock forming the top and the entire western face of the ridge. Toward the north a lower ridge of trap is found between the other two. West of the western of the lofty trap ridges is the reservoir. At a very low stage of the water in the reservoir an island is exposed which is composed chiefly of the quartzitic sandstone, but which also shows trap on the western side. Crossing the eastern brook entering the reservoir from the north, a trap dike is encountered, then quartzitic slate, then more trap. Northward these trap exposures increase in elevation and form the eastern side of a low ridge lying approximately along the middle of the reservoir valley. Near the northern end of this region inclusions of the quartzitic slate can be seen in the trap. The slate is found also west of this trap ridge.

The Paradise-Hanging Rock valley is undoubtedly occupied altogether by the quartzitic slate, intersected by coarse trap, the quartzitic slate forming the valleys and the trap the ridges.

In the present state of knowledge on the subject, no place for these quartzitic schists can be found in the Carboniferous series. They either overlie or underlie these rocks, and owing to their resemblance to rocks elsewhere with confidence adjudged pre-Carboniferous, they are also considered older than Carboniferous, and are believed to have been left as a great triangular mass, bounded east and west by fault planes along which the Carboniferous strata dropped down. Whether the diabasic rock preceded or anteceded the period of deposition of Carboniferous rocks is not known. Attention should, however, be drawn in this connection to the frequency of dike action in the pre-Carboniferous shales of the Newport Neck region, and to a less degree in the green pre-Carboniferous rocks of Sachuest Neck and in the Conanicut Carboniferous shale series.

All of these interpretations of the geological structure of the exposures

of the Paradise and Hanging Rock series may seem rather forced, but they appear to be the only ones consistent with knowledge obtained elsewhere in the field, which rests on a more secure foundation. No effort has been spared to secure a more ready and simple explanation, but the exposures are not sufficiently numerous and conclusive, and the interpreter is driven to theorizing where more exposures would make this unnecessary.[1]

ISOLATED CONGLOMERATE EXPOSURES NEAR EASTONS POND AND NORTHWARD.

On the west side of the Eastons Point anticline it will be remembered that there is evidence of synclinal structure, and that at the east end of Eastons Beach the dip is about 15° to 20° E

West of the northern half of Eastons Pond, below the greenhouses, bluish sandstone, darker shaly rock, and some conglomeratic layers composed of pebbles, *not* recalling the coarse conglomerate series, are found. They do not seem to vary far from a horizontal position.

Three-quarters of a mile northward, in the field, north of a farmhouse north of the east-west road, much coarser conglomerate is exposed, with quartzitic pebbles of the Paradise Rock type up to 8 inches in length, but usually only 3 to 4 inches long. It seems to be part of an anticlinal fold pitching northward about 10° and trending N. 16° E. On the western side the dip is about 15° W.

A somewhat similar conglomerate is exposed a mile northeastward, west of the western road corners of a triangular plat of land formed by the public ways. The pitch here seems to be also low northerly, the strike being apparently N. 7° W., dip very low west, but the exposure is not suitable for the exact determination of these features.

The precise relation of these exposures to the general shale series northward and westward is not known.

According to the interpretation given by Professor Dale (loc. cit.), the great Purgatory conglomerates overlie the Aquidneck shale series, but dip under the Newport Cliff exposures. To the writer the cliff exposures appear to belong to the horizon of the Sakonnet sandstones and the lower half of the Purgatory conglomerates, though he does not know of any very conclusive evidence for either view.

[1] Consult, on the same area, T. Nelson Dale, Boston Soc. Nat. Hist., Vol. XXII, 1883, and Proc. Newport Soc. Nat. Hist., 1885.

MIANTONOMY HILL AND COASTERS HARBOR ISLAND CONGLOMERATES.

MIANTONOMY HILL.

A little over a quarter of a mile south of the top of Miantonomy Hill coarse conglomerate is exposed, south of a house along the edge of a field. It is again exposed northwest of the house, trending northward. Northward it forms the entire structure of Miantonomy Hill. Interbedded sandstone along the entire northern margin of the hill shows the conglomerate to be apparently horizontal from east to west, but in fact dipping southward at an angle of about 15°. There is apparently a low eastward dip at the northeast angle of the hill.

The pebbles of this conglomerate are of the largest size, at times more than 2 feet long, and they have not been elongated. They are evidently of the Purgatory type.

Northward, between Miantonomy and Beacon hills, there is exposed considerable dark-blue sandstone, shaly in places, dipping low southward.

BEACON HILL.

On the summit of Beacon Hill more conglomerate is exposed. The pebbles on the average are of much smaller size and usually do not exceed 8 inches in diameter. The series has evidently been slightly folded by an east-west thrust, as may readily be detected by following the line between the conglomerate and the overlying interbedded sandstone at the north end of the hill summit. The pitch is again about 15° S., and the westward dip on the northwest side of the hill suggests that the conglomerate is here descending into the valley. The conglomerate of Beacon Hill evidently underlies the much coarser conglomerate of Miantonomy Hill.

FIELD EXPOSURES.

In a field west of Miantonomy Hill and just east of the railroad is a series of coarse conglomerate exposures, striking N. 8° W. and dipping 45° E. The most western exposure has smaller pebbles, the more eastern ones larger pebbles, some of these attaining a length of $1\frac{1}{2}$ to 2 feet. Fossil oboli were found in one of the pebbles. Interbedded sandstones disclose the dip. This dip indicates a synclinal structure between these

exposures and those of Miantonomy and Beacon hills. The southward pitch, so well shown on the hills named, indicates how it is possible to have the regular dark-blue and black shale along the railroad cut north and south of Coddington Cove along with a total disappearance of the conglomerate series. Anyone standing on the top of Beacon Hill, and knowing the distribution of the shale series northward, can not fail to be convinced that the coarse conglomerates overlie that series.

CODDINGTON NECK.

The bluish-black shale series underlies Coddington Neck. Almost continuous exposures occur along the western side of Coddington Cove, and form the two main hills of the neck. At the north end of the neck these shales strike N.-S. and dip 70° to 80° W. Farther west these dips are less steep. About 225 feet southwest of the most northern point of the neck fern-leaf impressions were found in the bluish-black shale. At the northwestern angle of the neck coarse conglomerate appears, still dipping westward, overlying conglomerate with medium-sized pebbles. Farther along the coast southwestward, more conglomerate with medium-sized pebbles is seen; then brownish sandstone, again the former conglomerate, and then coarse conglomerate appear in succession, the second exposure of coarse conglomerate appearing at the western angle of the shore where it begins to turn southward. The dip of the coarse conglomerate here is very steep eastward. In other words, a very compressed syncline has brought down the base of the coarse conglomerate series. Southward from the more southern conglomerate exposure, the bluish-black shale series is seen to contain frequent narrow intercalations of a whitish sandy rock.

BISHOP ROCK.

The same series of blue-black and coaly black shales, with bands of whiter rock, is exposed on the northwest side of Bishop Rock, striking N. 40° E. on the north side, toward Coddington Neck, and curving westward and then southward so as to strike about N. 25° E. on the west side of the rock. The series dips westward about 60°. Underlying it, southeastward, is medium-sized quartzitic conglomerate, and beneath that is coaly shale, evidently much folded and contorted. Fragments of arkose and other rocks appear in the coaly shale as though they were pebbles, but the

appearance of some of the larger fragments suggests that they once formed continuous beds intercalated in the coaly shale. In that case the occurrence of arkose in this shale is of interest. It will be remembered that arkose is associated with coaly shales on Sachuest Neck. It is believed there to overlie a greenish shale and conglomerate, possibly comparable with the Little Compton green shales. It derived the materials for the arkose in part from the coarse-grained granites on the south and east.

The granite nearest to Bishop Rock is $2\frac{1}{2}$ miles distant, at the southern end of Jamestown, on Conanicut, and at the southern end of Newport Cliffs and on the adjacent part of the neck. The nearest exposures of green shales are on Goat Island, Rose Island, and Freebody Hill. Nowhere can these rocks be brought in close relation with one another so that their relative age may be determined. The arkose on Bishop Rock seems to belong to a horizon not far from the coarse conglomerate on the western side of Coddington Neck, and probably occur just beneath the same. Similar arkose occurs near the southern end of Coasters Harbor Island.

COASTERS HARBOR ISLAND.

The very coarse conglomerates, with pebbles often 1 foot and at times 2 feet long, so well shown on Miantonomy Hill, are again well shown on Coasters Harbor Island. No elongation of the pebbles is observable here. The strikes and dips are variable. The most southern exposure of conglomerate on the east side of the island has a strike N. 65° E., dip 40° to 50° NW. North of a small indentation of the coast the strike remains N. 65° E., but the dip becomes only 20° NW. Within a short distance northward the strike changes to N. 80° W. and the dip becomes 60° NE., and along the northeast coast the strike is N. 30° W. and at various localities the dip is 80° to 85° E. West of a small embayment the rocks of the northern promontory of the island seem to be in part folded, and elsewhere dip 80° W., striking N. 10° E. In an embayment west of this promontory sandstone is exposed, the apparent dip, which may be cleavage, striking N. 35° E., dip southward. At the northwest angle of the island the strike is N. 30° E., curving southward to N. 10° E. and N.-S., while the dip is constantly eastward, about 40° E. northward, becoming less southward. Southward carbonaceous sandstone and fine conglomerate are faulted against the coarse conglomerate, which is almost horizontal, and

then the strike suddenly becomes N. 80° W., dip 40° S., changing to N. 20° W., dip irregularly south, after which carbonaceous shales and sandstones make their appearance, occasionally showing conglomerate, the strike being approximately N.-S., and the dip 45° E. Southward, along the southwestern border of the main body of the island, coarse conglomerate is seen again, striking at first N. 40° E., dip 40° to 20° E.; then, as the shore turns southeast, the strike becomes N. 45° W., then N. 10° W., dip low east, the conglomerate becoming less coarse. Farther southward dips of 30° E. are noticed, and then, as the shore turns southward, green fissile shales, similar to the Conanicut shales, make their appearance.

At the southwest angle of this tongue of the island, arkose with thin layers of carbonaceous shale outcrop, with strike E.-W., dip 40° N. The rock south of the arkose and forming the southern end of the island is a greenish rock, which provisionally is here placed with the Newport Neck series of shales. Near the arkose it strikes N. 30° W., dip 40° E., and eastward N. 50° W., dip 25° E. Similar arkose is found on Bishop Rock and on Rose Island.

The coarse conglomerates of Coasters Harbor Island are evidently to be associated with the Miantonomy Hill conglomerate. The occurrence of almost constant eastward dips along the western side of the island is to be emphasized. The discussion as to the relationship of these conglomerates to the green shales at the south end of the island is deferred until the Harbor Islands are taken up.

NEWPORT HARBOR ISLANDS.

In this connection the description of the occurrence of the green shales at the southern end of Coasters Harbor Island should be again noted. Off the shore to the south of the island additional exposures of the green shales occur. They are considered to be of pre-Carboniferous age.

GULL ROCKS.

The main rock is occupied by a light-house. The pre-Carboniferous green shale here includes a more sandy, coarser variety of that rock, dipping about 20° N. A short distance southward is another exposure of similar nature, also dipping northward.

ROSE ISLAND.

The main body of Rose Island, all except the narrow tongue projecting northward, is composed of the greenish rock already mentioned as occurring on the Gull Rocks and at the south end of Coasters Harbor Island. The strike, as heretofore, is approximately E.-W., the dip 15° to 20° N. Some of the layers are coarser and resemble sandstone, while others are tinted purplish, as at Gull Island light-house. They are considered to be of pre-Carboniferous age.

North of the green series of rocks on the eastern side of Rose Island arkose appears. It seems to strike north-south and dips almost vertically. Farther north, forming the lunate extension of the tongue, are coaly sandstone and shale, with strike N. 25° E. and very steep dip, perhaps 70° W. On the western side arkose layers occur also southward toward the contact with the green shales, green shales coming in contact with the arkose as though brought together by a fault.[1] Reference has already been made to the arkose on Bishop Rock and Coasters Harbor Island.

CONANICUT ISLAND.

The arkose northwest of the granite area east of Mackerel Cove has already been described. Farther eastward, also north of the granite, occurs a pre-Carboniferous greenish rock, here called the Dumpling rock.

LINE OF SEPARATION BETWEEN CARBONIFEROUS AND PRE-CARBONIFEROUS ROCKS.

If now the northern line of outcrop of the western part of the granite and the pre-Carboniferous greenish Dumpling rock farther eastward on Conanicut be connected with the northern exposures of the green shales on Rose Island, the most northern exposures of green shales on Gull Rock Island, and the most northern of the green shales exposed along the southern end of Coasters Harbor Island, east of the arkose exposure, then it will be noticed that arkose occurs immediately north of this line at Mackerel Cove, Conanicut, on the southern end of the tongue of land extending north from Rose Island, and at the southwest corner of the tongue of land at the south-

[1] Prof. T. Nelson Dale suggests that unconformities between the Cambrian and Carboniferous are quite natural. There may be an unconformity here, but the abrupt linear contact between the arkose and the green shale, with the very marked variance between their dips and strikes, seems to exceed that of ordinary unconformities. There is no direct evidence that the Carboniferous arkose is resting upon the eroded surface of the Cambrian shale.

ern end of Coasters Harbor Island. The arkose is of Carboniferous age. The greenish rocks south of this line are supposed to be of pre-Carboniferous age.

In the light of this interpretation attention may be called to the facts that a north-south line along the middle of Mackerel Cove probably separates the pre-Carboniferous granite from the Carboniferous Conanicut shales on the westward, and also that a line extending along the western margin of the land, just offshore from Coasters Harbor Island, to the end of Long Wharf, and thence more east of south, east of the Spindle or Little Lime Rock to the southeast corner of Newport Harbor, then southeast, east of the granite exposures in Morton Park, south of Newport, and along the middle of Almys Pond, represents the dividing line between the pre-Carboniferous rocks on the west and the Carboniferous series on the east of this line. Thence the line extends eastward north of Sheep Point. All of these lines are believed to be due to faulting.

GOAT ISLAND AND LITTLE LIME ROCK.

The pre-Carboniferous green shales[1] have been reached in deep wells on Goat Island, and they occur on Spindle or Little Lime Rock, and they occur again as a series of rocks following each other in a north-south direction which are exposed at low tide southeast of Lime Rock. The dip and strike of these exposures were not carefully investigated, there being no means at hand of distinguishing cleavage from real stratification.

FORT GREENE.

South of Fort Greene Park carbonaceous black shales are well exposed along the shore. They are banded here with thin layers of a whiter, sandy rock, recalling the thicker interbedded white rock on Bishop Rock and on the west side of Coddington Neck. Thin seams of coal, or at least of very coaly shale, are said to have been struck at various times in the cemetery a quarter of a mile east of Fort Greene Park.

MORTON PARK AND SOUTHWARD.

Granite is well exposed in the western half of Morton Park. Toward the southeastern end of the grounds sandstone and blue-black shaly rock are seen striking east of north and dipping steeply westward. A better set

[1] The author does not distinguish between shales and slates or phyllites in this part of the report.

of exposures occurs half a mile southward, east of Almys Pond. Here sandstone, shaly sandstone, and conglomerate are interbedded. The conglomerate contains medium-sized pebbles of a quartzitic rock. Here also the strike is a little east of north and the dip very steep westward.

NORTHEAST LINES OF POSSIBLE FAULTING.

It may be noticed that a line connecting the most northern exposure of the greenish Sheep Point rock, along the eastern end of Bailey Beach, with its most northern exposure on the east side of Newport, north of Sheep Point, takes a northeast direction, and north of this line lie the Carboniferous rocks of the Newport Cliffs, evidently faulted against the older series. Moreover, along the northeasterly trend of the coast forming the southern border of Newport Harbor, the pre-Carboniferous green shale series, elsewhere called the pre-Carboniferous green shale of Newport Neck, occurs at several localities. Little Lime Rock and the series of green shales southeast of that locality have already been mentioned. Lime Rock itself belongs to this shale series, although itself composed of limestone.

The promontory a quarter of a mile southwest of Lime Rock, consisting of green shale and limestone, and the similar exposure northeast of the stables on the southwest side of Brentons Cove belong to the same shale series.

On the other hand, the rocks immediately south of the exposures just mentioned, which form the neck proper, are granite eastward, and a greenish and purplish fine-grained rock of uncertain character, looking like argillite, westward, as will be seen from the map, or from the description of the rocks forming the neck.

CARBONIFEROUS ROCKS ALONG THE NEWPORT CLIFFS.

The discussion of the series of rocks forming the cliffs at Newport has been left to the last, since least is known about them. It was intended to prepare a careful detailed section of these beds, but considering the small amount of time at the writer's disposal and the inaccessibility of these rocks except at low tide, it was decided that the time required could be more profitably employed elsewhere. This was especially the case since the cliff exposures could not be definitely brought into relation with others of known stratigraphic position.

The section along the cliffs at Newport, from Easton's Beach to the Forty Steps, includes about 175 feet of rock, the strike being, in general, north-south, and the dip variable westward, but averaging 45° W. The following notes will give an idea of the section disclosed: Southward from Eastons Beach, going upward in the section, 3 feet of coaly shale, 29 feet of sandstone with shaly layers, dip 20° W.; 4 feet of conglomerate with pebbles up to 4 inches, dip 45° W., and 32 feet of sandstone. Thence, going down in the series, the conglomerate and the sandstone, containing some conglomerate layers, and dipping 50° W., are passed again. Beneath occur 19 feet of coaly black shale, containing impressions of fern leaves, 15 feet of conglomerate with pebbles up to 4 inches in diameter, 22 feet of sandstone, and an unknown thickness of carbonaceous shaly sandstone, disappearing seaward, these last being the lowest rocks exposed along the cliff. Southward, in ascending order, the cliffs expose 20 feet of conglomerate and 23 feet of shaly or fine-grained sandstone, dipping 80° W. Southward, in descending order, the conglomerate occurs again. Then in ascending order are found again the coaly shale and sandstone; then 7 feet of conglomerate, 11 feet of shaly sandstone and coaly shale, 11 feet of conglomerate, 40 feet of carbonaceous sandstone and coaly shale, 8 feet of conglomerate, 27 feet of dark carbonaceous shaly sandstone, and high in the bank, just before reaching the Forty Steps, and again on the south side of the steps, a layer of conglomerate. At the steps the dip has become very low eastward, the pitch being plainly southward, about 15°.

The total thickness of Carboniferous rocks south of Forty Steps does not exceed 225 feet.

The conglomerate at the Forty Steps is 11 feet thick. Overlying it are, in ascending order: 11 feet of black shale and gray sandstone, almost horizontal; 11 feet of conglomerate, west of a fault, dip 40° W.; 11 feet of sandstone and shale, 5 feet of conglomerate, dip steep west; 24 feet of brownish shaly rock; more faulting; 9 feet of conglomerate, some of the pebbles being a foot long; more faulting; 13 feet of coaly shale, having a steep west dip.

After the coarse conglomerate with large pebbles comes in, a short distance south of the Forty Steps, layers of very coarse conglomerate are seen all along the shore as far as Ochre Point. It is probable that a careful study of the section along this part of the coast would show that there

are only a few layers of very coarse conglomerate present, but that these extend for a long distance along the shore, their continuity being interrupted by small faults. A detailed description of the southern part of this section, containing the coarse conglomerate layers, is of little value until the effect of the faulting has been clearly determined. In a general way it may be stated that the lower coarse conglomerate layers alternate with coaly shale and sandstone beds, as do the lower conglomerate layers containing relatively smaller pebbles north of the Forty Steps. The upper coarse conglomerate beds are associated with a series of greenish or brownish-green sandstones and shales, which are best exposed farther west and up the cliffs in the recesses of the shore north of Ochre Point.

At the promontory south of the Forty Steps the rocks dip low east. In the recess of the shore southward the dip is 40° W. At the next promontory southward the dip is again very low west, and in the recess southward the dip is steeper west again. Southward the faults become more frequent and the steep western dips are more common.

The coarse conglomerates and the associated greenish shales and sandstones which occur higher in the series, and which are exposed in the recesses of the shore northeast of the Cornelius Vanderbilt mansion, are exposed all along the northern shore of the cove west of Ochre Point. If the rocks be here carefully examined at low tide, the conglomerate layers will be found to be usually not thick, but they can at times be followed for considerable distances along the shore. They show the presence of various small anticlines and synclines, especially near Ochre Point, and also east of an observation house upon the sea wall farther westward. The series in general, however, is evidently almost horizontal, dipping as a whole very low westward.

Along the northern side of this cove a few of the shale layers associated with the coarse conglomerate are in places black rather than green, especially near the western side of this shore of the cove.

The total thickness of the formation south of the Forty Steps does not seem to exceed 225 feet, due allowance being made for faulting, so that the total section of the cliff series so far seems to be about 400 feet. The most striking geological feature of the series is the southward pitch of the folds. This is often very low, but at times becomes very steep southward, especially at the Forty Steps, and at another promontory exposing coaly

sandstone and shale farther southward, where the pitch must be at least 15° S. This southward pitch is again well seen along the northern margin of the cove, west of Ochre Point, where, however, it is very low south. It continues to be shown at the northwestern angle of the cove.

The southward pitch of the folded series last described would certainly carry it beneath the black coaly shale series exposed along the western side of the cove almost as far south as Sheep Point. This series of coaly shales and black carbonaceous sandstones contains abundant fern leaves. It strikes approximately north-south and dips steeply westward, but near its northern end it looks very much as though it overlies the green coarse conglomerate series forming the north side of the cove. Arkose is found in the northwestern angle of the cove. Its association with coaly shale recalls similar exposures on Sachuest Neck. There may be faulting here.

When the very marked southward pitch of the cliff series of conglomerates is considered in connection with the marked southward pitch of the Eastons Point anticline and the similar pitch of the rocks on Miantonomy and Beacon hills, it seems as though the cliff conglomerates might represent a southern extension of the coarse conglomerates of the last-named localities and a westward continuation of the Purgatory conglomerate. The failure of the coarse conglomerate to crop out along the western hill slopes of Newport and at points southeast of the Miantonomy exposures is, however, difficult to explain if this be the structure. The conglomerate layers in the sandstone east of Almys Pond are hardly satisfactory evidence of the former continuity of the coarse conglomerates between Eastons Point, the Newport Cliffs, and Miantonomy Hill. In any event the Newport Cliffs would represent only the basal part of the coarse conglomerate section. The Fort Greene and the Newport Cemetery coaly shales seem to belong beneath the coarse conglomerate stratigraphically.

Newport itself seems to be underlain by strata belonging to the Aquidneck series (see footnote on page 372). If this be true the Newport Cliffs may represent a section formed by the sharp synclinal infolding of rocks along the trend of the cliffs. This synclinal structure was accompanied by considerable subsidiary folding, and involved the lower part of the conglomerate series. A similar strong axis of folding seems to have been present off the western side of Coddington Point and Coasters Harbor Island.

Southward it seems to have ended in a fault, and both systems of infolding seem to have been accompanied by much subsidiary folding and faulting.

Fossil ferns are found in the carbonaceous shales north of Sheep Point, especially at the promontories a little over a quarter of a mile north of that point. Fossil oboli occur in pebbles at various points a short distance north of Ochre Point.

NEWPORT NECK AND SOUTHERN CLIFF ROCKS.

GREENISH ROCK IN THE CLIFFS SOUTHWEST OF SHEEP POINT.

From the western side of the cove west of Ochre Point, along the shore almost as far as Sheep Point, extends a series of black coaly shales, having a general strike parallel to the shore and dipping westward at various angles averaging about 50°. A short distance north of Sheep Point a greenish rock occurs, whose nearest outcrops are within a few feet of the coaly shale; but while the general trend of the black shales is about N. 20° E., the line of contact between the shales and the green rock runs about N. 45° E., as near as can be determined, and nearest the line of contact the shales are much crumpled and the green rock has been so much sheared that it slightly resembles a shale. At the southern end of the point the shearing has ceased and the rock is seen to be in reality massive. Several hundred feet south of Sheep Point, at one of the projecting angles of the shore, the greenish rock has included a rather large mass of a rock which is bluish and very fine grained when fractured, but which has a whiter and a more stratified appearance where subjected to weathering. Macroscopically it therefore has the appearance of a stratified rock much contorted and cleft, the crevices being penetrated by the greenish rock. Fragments of a similar rock occur farther southward and present at times an appearance very much like that of a stratified rock. Their nature can be determined only by microscopic examination. Dikes of a whitish or faintly pinkish aplite are also not uncommon, although occurring more commonly in the granite area farther southward. In places the greenish rock presents the appearance of flow structure. About three-eighths of a mile south of Sheep Point the greenish rock is abruptly terminated by contact with a coarse-grained granite with large phenocrysts of feldspar. The greenish rock here has a more evident granular structure than usual and has the appearance of having once con-

tained numerous cavities toward the contact, the cavities having later been filled with a greenish mineral. This occurrence of apparently amygdalar structure is itself suggestive of the igneous origin of the greenish rock. But it may result from replacement of contact minerals originally due to the intrusion of the great granite mass into the greenish rock.

GRANITE AREA AT THE SOUTH END OF THE CLIFFS.

The granite nearer low-tide mark is in actual contact with the greenish rock, maintaining its coarse grain and the large size of its phenocrysts to the contact. Farther from low tide, somewhat nearer the cliff walk, a band of the pinkish fine-grained aplitic rock already mentioned intervenes, the granite terminating abruptly against this rock, preserving the coarseness of its grain and the large phenocrysts as far as the actual contact with the pink aplite. The pink aplite at this point begins with a much finer grain, and preserves this to its actual contact with the green rock. The width of this band of pink aplite is 6 to 8 inches. Toward the sea it partly includes fragments of the greenish rock between its mass and the granite. Nearer shore it enters the granite mass at one point with a less sharp contact, allowing the granite to come in contact with the green rock. The pinkish aplite penetrates the greenish rock in dikes along the shore, one of these dikes being much coarser in grain and showing more granitic character, having apparently possessed both macroscopic feldspar and hornblende, but no phenocrysts, and not attaining the coarseness of grain of the main granite mass. Some of these facts suggest that the granite is more recent than the greenish rock. Nothing definite can be stated. In many places the granite is itself frequently cut by the pinkish aplite. The most northern exposure of the granite on the east shore is a little north of the great bend where the southerly trend of the shore from Sheep Point changes to the more rugged southwestern trend of the shore toward Coggeshalls Point. Thence it occupies the entire line of the shore as far as Baileys Beach, south of Almys Pond.

A greenish rock, appearing like a dike, occurs in the most northern exposure of the granite just before reaching the beach. Another greenish rock, parallel to this, contains brecciated fragments—probably of the same general mass, but looking whiter in consequence of weathering—and also one pebble of undoubted quartzite. At the eastern end of the

beach there occurs an additional mass of the greenish igneous rock, traversed in all directions by whitish streaks. This is probably a continuation of the greenish rock from the eastern shore, near Sheep Point.

GRANITE AREA ON EASTERN NEWPORT NECK.

At the western end of the beach, south of Almys Pond, is found a reddish granite, to a certain extent resembling the groundmass of the porphyritic granite already described, but lacking phenocrysts. Toward Lily Pond the granite has changed from bright red to a much darker red, due to the presence of an abundance of some darker mineral. These granites are frequently cut by the pinkish fine-grained aplite, whose character as a dike rock is unquestionable in all of the more western exposures. This second granite area includes all of the rock between Almy's and Lily ponds, the hill immediately west of Lily Pond, and thence northward as far as the southern margin of the harbor at Newport, excepting perhaps a narrow border along the shore, which seems to be made up of greenish shales similar to those found elsewhere about the harbor. It occurs also as a medium-coarse granite north of Almys Pond, in the western part of Morton Park.

GREENISH AND PURPLISH ARGILLITIC ROCK OF MIDDLE NEWPORT NECK.

West of the granite area, as far as Brentons Cove, the western side of Rocky Farm, and Prices Neck, occurs a fine-grained rock, varying in color from green to dark purple, in places epidotic, which has usually been called an argillite. It contains traces of banding very similar to stratification, but which might be interpreted as flow structure. In the northwestern part of this area Prof. T. Nelson Dale found a fragment of undoubted quartz-porphyry embedded apparently in a cement composed of clastic material. This would indicate that at least a part of the area was of sedimentary origin. This rock is closely related to the Dumpling Rock and the greenish rock southwest of Sheep Point.

PRE-CARBONIFEROUS GREEN AND PURPLE SHALES OF WESTERN NEWPORT NECK.

The western part of Newport Neck, including all the area west of a line drawn through the marshes from the western side of Prices Neck to the southern end of Brentons Cove, is occupied by a series of shales.

Their usual color is greenish, and very frequently whitish; more sandy, thin layers are interbedded, giving the rock a banded appearance. This banded character is well seen at various points on the east side of Brentons Point. Sometimes the rock is rather quartzitic and is cleaved like the rock on the hill east of Browns Point, east of Sakonnet River; one locality of this kind is found along the east side of the road leading northward into the Fort Adams grounds and southwest of Brentons Cove. Not infrequently the shales are purplish in color, and where this is the case thin layers of limestone are often intercalated in the shales. The same feature was noted in the Little Compton shales, and suggests the identity of these shales. Calcitic layers not being known from undoubted Carboniferous rocks, nor having been found elsewhere in the field, suggests that the Brenton Point shales are of pre-Carboniferous age.

Layers of calcite are especially numerous around the vicinity of Pirates Cave and the shore just south of the irregular headland a quarter of a mile southeast of Castle Hill. Along the summit of Castle Hill some masses of limestone occur, but it is not certain whether the material is in situ. Around Brentons Cove, however, these interbedded calcitic layers are thicker and apparently more common.

The average strike of the above-described shales is N.-S., and the dip 30° to 40° E. However, on the southern and western shores of Brentons Point the strike is frequently N. 30° W., varying at times to N. 70° W., and the dip occasionally becomes almost horizontal, and near the southwest end of Brentons Point and north of Pirates Cave becomes locally even westward. The most northern exposure of the green shales on the neck is south of the wharves on the east side of Fort Adams. A sixth of a mile south of the wharves, at a prominent angle of the shore, the green shale contains thick limestone layers.

The existence of these limestone beds in the green shale series is of importance, since nothing similar occurs in the undoubted Carboniferous rocks. A limestone bed is found northeast of the stables on the prominent angle of the shore at the southwest side of Brentons Cove. It strikes about N. 10° E. and dips steeply eastward. A quarter of a mile northward, near Fort Adams, the limestone occurs again, as already mentioned. Here it is much crumpled, but seems in general to strike N. 70° E., dip southward.

A much thicker bed forms the two exposures at the Lime Rock light-house, whose strike seems to be approximately east-west, dip steep southward. A bed of limestone more nearly agreeing in thickness with the two occurrences above described is found on the promontory a quarter of a mile southwest of Lime Rock. Here again it is prominently associated with the green shale series, and strikes N. 50° to 60° E. and dips steeply northward. Limestone beds are also said to have been struck in penetrating the green shales which underlie Goat Island. These thicker calcite beds, which occur along the southern border of Newport Harbor, are in places coarsely crystalline in consequence of metamorphism, but usually show a fine grain, and, though white within, weather to a peculiar light-brown color. The thinner beds of calcite, however, south of Pirates Cave and in the Little Compton shales are usually tinted with pink or reddish purple.

So far, in all eastern Massachusetts and Rhode Island, only two formations of Paleozoic age have been discovered, the Cambrian and the Carboniferous. The Carboniferous is nowhere known to contain true limestone beds of sedimentary origin.[1] The Olenellus Cambrian at almost all of the localities where it is known to occur in these States contains limestone interbedded with shales, resembling especially the thinner limestone beds of the green and purple shale series in the southern Narragansett Bay region. In view of these facts search for fossils was made in these southern localities, but without success. The determination of the age of these shales as pre-Carboniferous therefore rests upon two facts—the presence of limestone layers and the entire absence of carbonaceous material in any of these beds.

If, in addition, the relations of the arkose to the green shale series at Sachuest Neck be taken into account, and the occurrence of the arkoses at the line of contact between the green shale series of supposed pre-Carboniferous age and the Carboniferous rocks on Conanicut, Rose Island, and Coasters Harbor Island be considered, an assumption of the pre-Carboniferous character of the green shale series affords a more ready explanation of the cause of its present distribution, faults having thrown pre-Carboniferous rocks upward on the south side of the faults, against higher-lying Carboniferous rocks.

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[1] As will be seen from Mr. Woodworth's part of this monograph, there are limestone deposits in the Wamsutta series, but these are probably of secondary origin, owing their formation to the injection of igneous rocks in the area in which they are found.—N. S. S.

SHALE SERIES FROM CODDINGTON COVE TO LAWTONS VALLEY.

In the railway cut southeast of Coddington Cove the bluish-black shale is exposed for a quarter of a mile. The cleavage dips 15° to 20° W. In the most eastern part of the indentation at Coddington Cove black shale is exposed again, the cleavage dipping 10° to 20° E. Three-quarters of a mile northward, south of the angle of the shore directly east of Gould Island light-house, the dark carbonaceous, often black, shale is seen in the bank. It is much cleaved, the dip of the cleavage being low eastward. Northward, in the concave curve of the shore, gray-blue sandstone is interbedded with the coaly shale. The cleavage still dips only 5° to 10° E., but the real stratification shows strike N. 21° E., dip 25° to 30° E. At the north end of this cove the most western part of the shore line shows more of the carbonaceous sandstone interbedded with coaly shale; strike N. 12° W., dip about 60° E. A few fern-leaf impressions occur in the shale here. Over the sandstone lies more of the coaly shale. The sandstone and shale continue to be exposed for half a mile northward, the strike changing at the north end to N.-S., dip 50° E. The cleavage is low west. Along the railroad southward, near the north end of the cut, greenish shale and sandstone occur, the latter including thin layers of fine conglomerate. These greenish rocks evidently belong in the blue shale series, but overlie the shore exposures. Along the east-west road northward, nearly half a mile from shore, black shale is exposed. Where the next creek northward crosses the road from Newport to Bristol Ferry, the greenish-blue shale series is exposed in the creek bed west of the road. A little south of the mouth of this creek coaly shale and sandstone are found in numerous fragments in the banks, as though occurring in situ farther back from the face.

East of Carrs Point and south of Lawtons Valley the north end of the railway cut shows coaly shale and carbonaceous sandstone; strike N. 15° E., dip 15° E., as far as could be determined; the exposure is not satisfactory. The blue shale series is exposed along Lawtons Valley, about half a mile south of the point where this valley crosses the Newport raod, and where the east-west road leaves the Newport road eastward for the Glen region on the east side of Aquidneck. Up the road eastward the blue-black shales are exposed as far as the brow of the hill. A little

northward from this road, along the Newport road, the blue-black shale fragments, apparently almost in situ, show frequent fern-leaf impressions. Farther northward, in the roadside, greenish shale occurs. These green shales are seen again east of the road on the northwestern side and along the summit of the hill, and are overlain on the eastern side of the hill by fine-grained grayish-green sandstone striking about N.-S. and dipping 30° to 40° E. This sandstone is exposed again northward along the strike on the west side of the road. This exposure serves to confirm the evidence of the general eastward dip of the rocks along the western side of the island, a feature so much better shown to the northward. The dark greenish-blue shales are also well exposed where Lawtons Valley crosses the east-west road leading toward the Glen.

GREENISH-BLUE SHALES OF SLATE HILL AND SOUTHWARD.

Along the East Newport road, east of the highest part of Slate Hill, bluish shale tinged with green is exposed west of the road. A quarter of a mile southward the shale, here colored dark blue, at one point verging to black, occurs interstratified with sandstone. The strike is N. 15° E., dip apparently low E., about 10°. Half a mile southwest along the road, where it begins to descend the hill more rapidly, the greenish-blue shale is exposed, and three-eighths of a mile farther on it is seen for the last time on the west side of the road. The isolated conglomerate exposure three-quarters of a mile farther southwest has already been mentioned.

SHALE SERIES NORTH OF LAWTONS VALLEY.

SHORE EXPOSURES NORTH OF COGGESHALL POINT.

Coaly shale is exposed along the shore three-quarters of a mile north of Portsmouth Grove Station and continues northward. Near Corys Lane fine-grained sandstone overlies the shale and contains plant impressions. North of Corys Lane the shore offers material for a detailed partial section as follows, in descending order, going northward:

Section north of Corys Lane.

	Feet.
Fine sandstone	15
Black coaly shale, containing *Sphenophyllum equisetiformis*, *Annularia longifolia*, and large fern-frond impressions	9
Sandstones, in places somewhat coarse	7

Section north of Corys Lane—Continued.

	Feet.
Black coaly shale	4
Sandstone	10
Coaly bed, with low eastward dip	20
Black coaly shale	4
Black shale and very fine-grained sandstone, with low eastward dip (about 10°), showing abundant traces of plant remains	9
Fine-grained sandstone	4
Coaly shale and fine-grained sandy rock, striking about parallel to the shore and dipping 20° E	8
Coaly shale	17
Black shale, dipping 10° to 15° E	15
Not exposed	5
Shaly sandy rock	1
Coaly shale	9

The section terminates a little over half a mile south of Portsmouth Mine Station, south of the mouth of the creek.

PORTSMOUTH MINE AND NORTHEASTWARD.

At the Portsmouth mine (see footnote on page 381) three beds of coal were formerly mined. The dip was about 35° SE., the strike having changed here considerably toward the east. The old dump shows coal, black shaly slate, and black sandstone, sheared until a part of this is also schistose. Calamites, *Annularia longifolia*, and many fern-leaf impressions occur here.

Three-quarters of a mile northeastward, on the hillside east of the railroad, a coal seam was also once opened, and the dump shows the same kind of rocks as at the Portsmouth mine.

A quarter of a mile south of the Bristol Ferry hotel the roadside shows coaly shale, striking apparently N. 35° E., dip 50° E.; not satisfactory.

A little south of the last exposure a road turns off eastward, toward the south end of Town Pond. Here carbonaceous sandstone, some of the layers coarse, contains fragments of carbonaceous shale, much crumpled, apparently by a force acting east-west.

A boring in Portsmouth, Rhode Island, examined by Mr. Collier Cobb, gave the following record as regards succession and thickness, but no account is taken of possible reduplication by faulting or folding. In this table argillaceous strata in superposition and variously denominated argil-

lite, slate, and shale fire clay in the original record have been grouped together as a single bed under the name argillite:

Record of boring in Portsmouth, Rhode Island.

	Feet.	Inches.
1. Below casing, fire clay	13	1
2. Argillite, dark colored, growing lighter and becoming friable downward	9	4
3. Argillite, in upper part slaty, banded and light gray, crossed by seams of epidote and magnetite	8	7
4. Gray sandstone		8
5. Drab slate	1	0
6. Gray sandstone, containing calcite	3	11
7. Brecciated slate	1	0
8. Carbonaceous argillite	2	1
9. *Coal*, with quartz impurities, brecciated	3	0
10. Carbonaceous argillite	2	6
11. *Coal*, some quartz in uppermost part	3	9
12. Slate		6
13. *Coal*, considered good up to 49 feet 10 inches	2	9
14. Quartz and slate breccia		2
15. *Coal*, filled with fine particles of calcite	3	0
16. Argillite	8	1
17. Argillaceous slate	2	4
18. Brecciated carbonaceous matter, containing quartz and some magnetite		4
19. Argillaceous shale	2	2
20. *Coal*, with quartz and iron pyrite		3
21. Argillaceous shale	4	7
22. Highly carbonaceous shale	6	2
23. Quartz, with fire clay	5	8
24. Fire clay, like top of hole	1	3
25. Argillaceous shale	2	8
26. Fine sandstone		4
27. Quartz; probably chlorite gives the green color to a part of the quartz		3
28. Argillite, dip 24°		5
29. Sandstone, showing feldspar and chloritic development	6	0
30. *Coal*, containing magnetite		1
31. Quartz, containing chlorite and pyrite		1
32. Sandstone	9	3
33. Argillite, brecciated	3	6
34. Sandstone	13	7
35. Quartz vein		1
36. Sandstone, discolored by iron oxide, with quartz veins, feldspar, and chlorite	16	5
37. Carbonaceous shale	4	1
38. Slate, drab in color, with iron pyrite	4	6
39. Carbonaceous shale, with quartz veins		2
40. Black shale, with small quartz veins and iron pyrite	4	7

	Feet.	Inches.
41. Argillite		6
42. Shale	7	0
43. Shale, black and carbonaceous, contains some quartz	2	0
44. Sandstone	4	8
45. Sandstone, more compact and modern than above	1	1
46. Sandstone		6
47. Sandstone	1	6
48. Slate, with crystals of iron pyrite	3	0
49. Quartz vein		1
50. Slate, crossed by small veins of quartz, calcite, and iron pyrite	9	4
51. Sandstone, dark and fine grained	4	11
52. Slate, very hard and fine grained	8	6
53. Sandstone, hard and fine grained	1	3
54. Shale, hard and black	7	4
55. *Coal*, a highly carbonaceous graphitic bed	2	1
56. Slate, hard	7	11
57. Quartz vein		1
58. Slate, hard	3	8
59. Shale, carbonaceous	5	8
60. Shale, sandy	4	6
61. Slate, hard and black, carbonaceous		5
62. Slate, hard, black, and sandy	7	11
63. Slate, hard and black		
64. Quartz vein		1
65. Slate, hard, black, and carbonaceous	3	6
66. *Coal*, full of quartz impurities		2
67. Slate	1	0
68. Sandstone, fine grained and hard	2	1
69. Quartz vein		1
70. Sandstone, fine grained	4	0
71. Sandstone, fine grained	2	1
72. Shale, hard, passing into a hard fine-grained sandstone	10	1
73. Shale, carbonaceous	2	2
74. Shale, arenaceous, passing into a fine sandstone	3	6
75. Sandstone, fine grained	2	0
76. Shale, carbonaceous	4	9
77. Shale, fine grained	1	2
78. Shale, sandy	3	7
79. Sandstone, gray, hard, and fine	3	9
80. Shale, black, fine grained		2
81. Shale, arenaceous, with bands of graphite	3	7
82. Shale, black	1	8
83. Sandstone, fine grained	2	3
84. Shale, black, with quartz		2
85. Sandstone, with quartz veins	3	3
86. Sandstone	6	0

	Feet.	Inches.
87. Graphite, impure	1	6
88. Sandstone	2	10
89. Shale, black and highly carbonaceous	1	6
90. Coal		2
91. Sandstone	3	9
92. Quartz vein		3
93. Sandstone	1	4
94. Quartz vein		1
95. Sandstone, gray	3	9
96. Slate, drab and hard	2	3
97. Slate, same as above	3	2
98. Sandstone		8
99. Shale, carbonaceous	1	0
100. Sandstone, fine grained	1	4
101. Shale, carbonaceous		4
102. Sandstone, gray		10
103. Sandstone, dark gray		3
104. Sandstone, lighter gray	5	0
105. Sandstone, dark gray	1	4
106. Shale, carbonaceous	9	8
107.	3	1
108. Sandstone, fine, filled with carbonaceous matter	1	6
109. Sandstone	1	8
110. Sandstone, coarser than above	1	3
111. Sandstone, with thin seams of carbonaceous matter	4	0
112. Shale, black and carbonaceous, dip 43°	1	9
113. Sandstone, dark gray		4
114. Shale, arenaceous, filled with carbonaceous matter	2	0
115. Slate, black	1	8
116. Sandstone, like that at 120 feet down		8
117. Shale, carbonaceous	1	10
118. Shale, arenaceous, with carbonaceous matter	1	2
119. Sandstone		4
120. Shale, arenaceous, with thin seams of carbonaceous matter	6	4
121. Shale, highly carbonaceous	2	0
122. Sandstone, hard and fine grained	1	0
123. Argillite	4	9
124. Sandstone	1	0
125. Argillite		10
126. Sandstone, hard and fine, with small calcite veins	1	3
127. Argillite, carbonaceous	2	0
128. Shale, arenaceous, containing, from one-eighth to one-fourth inch apart, very thin layers of granite	3	0
129. Sandstone, gray	3	3
130. Coal, filled with quartz, iron pyrite, and chlorite		1

	Feet.	Inches.
131. Argillite	1	5
132. Sandstone, with calcite veins and iron pyrite	1	0
133. Shale, carbonaceous	4	11
134. Sandstone, fine to coarse grained, with calcite veins	3	9
135. Sandstone, hard and darker than above	1	10
136. Sandstone, like above, with carbonaceous matter	3	5
137. Sandstone, fine grained, gray, entirely free from carbonaceous matter		6
138. Shale, carbonaceous	22	6
139. Sandstone, fine grained	1	6
140. Shale, carbonaceous		9
141. Sandstone, fine grained		1
142. Slate, hard, black, becoming carbonaceous toward end, dip 28° at top	4	0
143. Sandstone, hard, fine grained	1	1
144. Coal, broken and filled with calcite covered with iron pyrite, dip 63°		5
145. Sandstone, fine grained	3	2
146. Shale, carbonaceous	1	0
147. Sandstone, fine grained and indurated		10
148. Coal, brecciated and filled with calcite		2
149. Shale, hard black		6
150. Argillite	8	4
151. Shale, black, becoming carbonaceous toward middle and arenaceous at the bottom	7	4
152. Coal (carbonaceous breccia)		3
153. Sandstone		9
154. Sandstone, with small veins of calcite	1	0
155. Shale, carbonaceous		1
156. Shale, arenaceous	1	0
157. Shale, highly carbonaceous, dip 36°		2
158. Sandstone	1	3
159. Sandstone, gray	1	3
160. Argillite	3	8
161. Shale, carbonaceous	1	4
162. Shale, hard, fine, and arenaceous	2	6
163. Shale, arenaceous		11
164. Shale, arenaceous and carbonaceous between 440 and 442 feet down	22	1
165. Shale, carbonaceous	4	5
166. *Coal*, with veins of quartz near bottom	6	5
167. Sandstone, gray	1	0
168. Shale, carbonaceous	3	1
169. Sandstone, gray	3	10
170. Sandstone, dark gray and fine grained	2	3

To bottom of hole, 475 feet 11 inches, reached February 23, 1887, at 5.30 p. m.

LINE OF EXPOSURES THREE-EIGHTHS OF A MILE WEST OF THE NEWPORT ROAD.

Almost half a mile north of Lawtons Valley a much smaller stream gully is seen extending down the hillside. On the south side, near the railroad, carbonaceous black shale containing occasional fern-leaf impressions is exposed. The dip is apparently very low eastward. Farther up, the shale turns to bluish black. At the brow of the hill, south of the gully, there occurs a small conglomeratic layer. Toward the top of the gully sandy layers come in.

The creek entering the marshy pond south of Coggeshall Pond also shows dark blue-black shales, with interbedded sandy layers, in the banks south of the valley and near the railroad. The dip is at first 40° E., but becomes steeper eastward. The same series continues to be exposed farther up along the valley, the strike at one point being N. 30° E., dip very steep east. The rock contains sandy layers and in places also becomes very carbonaceous. At the brow of the hill north of the creek a coarse, thick, whitish sandstone layer shows a strike of N. 30° E., the dip apparently 60° E. Southward this sandstone terminates suddenly, but northward it continues for a long distance. To the eastward the shale series overlies this sandstone again. The sandstone contains in places a few small pebbles. It forms only a layer in the shale series.

The coarse sandstone is exposed again three-eighths of a mile east of north of the creek. Here again a few pebbles occur. Strike N. 12° E., dip E. Northeast of this locality the same coarse sandstone is overlain by carbonaceous shale; strike N. 20° E., dip 40° to 45° E. Southeastward, halfway between the last two exposures and the Newport road, bluish-dark shale is exposed at several localities, evidently overlying the coarse sandstone, and apparently dipping steep to the east. Northwest of the last sandstone outcrop dark-bluish shale is exposed. It belongs beneath the sandstone bed, but contains itself more sandy layers, and the dip is eastward, although apparently only 20°. The last exposure extends as far as an east-west road running to the beach. A quarter of a mile northward a projection at the northwestern angle of the hill shows a more greenish shale; strike N. 16° E., dip 60° E. Another exposure of the shale occurs a quarter of a mile northward, south of the brook. The shale,

more bluish in color, is seen again north of the brook, along the south side of an east-west road; strike N. 20° E., dip very steep eastward. In the fields north of this road the shale continues to be exposed, and just before reaching the road which crosses the 140-foot hill (see map, Pl. XXXI) southwest of a house the bluish shale is exposed, and contains a more sandy layer just south of the building; dip not certain, strike apparently N. 35° E.

SHALE SERIES AT BUTTS HILL.

Three-quarters of a mile northeast of Butts Hill, along the eastern Newport road, carbonaceous shale with fern leaves and other plant remains occurs. Strike N. 6° E., curving to N. 20° W at the north end of the exposure; dip 15° to 20° W. Northeast of Butts Hill, along the same road, just north of Chas C. Hazard's house, a coal mine was formerly worked. The strike of the beds is N. 15° E., dip 15° to 20° W. The structure of the northern third of Aquidneck Island is evidently that of a syncline.

All around the top of Butts Hill, especially in the neighborhood of the old fort, the bluish-black and coaly shale is frequently exposed. North of the old fort and just south of the road crossing the hill is an old quarry. Near the top of this exposure the blackish shale contains fern-leaf impressions. The dip of the shale is low, 5° to 10° S. In places there is evidence of much crumpling here by a force acting east and west, and the result is a series of narrow folds trending north-south and giving rise to variable east-west dips, generally to the westward along the east side of the hill. Butts Hill evidently lies in the trough of the syncline.

GREEN SHALES AND CONGLOMERATES OF THE NORTHERN SYNCLINE.

GREEN SHALES ALONG THE WESTERN NEWPORT ROAD.

Half a mile north of the point where the Newport road crosses Lawton Valley greenish-blue and bluish shales occur along the road and immediately westward. The strike is about N. 10° E., dip probably 20° E. A mile northward, on the east side of the road, greenish-blue slate and sandstone strikes N.-S., dip 20° to 40° E., as well as could be determined. A quarter of a mile northward, at an angle of the road, more greenish shale occurs. Three-eighths of a mile northward the green shale is seen exposed, east of the road corners, on the south side of the road. Green shales occur

also on the southwest and northeast sides of the hill immediately northward, and again, for the last time, a quarter of a mile northward, west of the road.

The green shales therefore form a series overlying the bluish-black shales, although evidently a part of the same and representing only the upper courses of the series.

PORTSMOUTH CONGLOMERATES.

A road leads from Portsmouth Grove Station eastward to the Newport road. An eighth of a mile southeast of the road corners conglomerate with quartzitic pebbles up to 10 inches in diameter is found. The trend of the exposures is about N. 10° to 15° E., but the strike and dip could not be satisfactorily determined. Northward, the same distance northeast of the road corners, bluish sandstone, varying to green, in places coarse, and with some layers of fine conglomerate, is seen. The trend of the exposures is N. 12° E. A quarter of a mile northeast of the crossroads the greenish slate is seen on the hillside nearer the Newport road, becoming more bluish eastward and merging into a more sandy rock toward the northeast, where it is more nearly in line with the previous exposure. Three-quarters of a mile from the crossroads, along the top of the hill, considerable sandstone occurs. It includes a narrow greenish shale layer, and at the southwest end a few thin conglomeratic beds, with pebbles not exceeding half an inch in diameter. An eighth of a mile northeastward, and the same distance from the next east-west road, greenish-blue shale again occurs westward, with gray sandstone eastward. A few layers are coarse, almost conglomeratic. North of the east-west road loose pebbles, similar to those usually found in conglomerates, occur with considerable frequency on the east side of the hill, east of the regular green shale exposures of the hill. Over three-fourths of a mile northward, an eighth of a mile northeast of the crossroads, begins a ridge extending N. 80° E., across the next road leading northward. This ridge is formed in the main of conglomerate, composed of quartzitic pebbles often 8 inches or longer in diameter, and containing fossil oboli. The conglomerate strikes N. 20° E.; the dips are difficult to determine, but seem to be in some places nearly vertical, in others less steep. A greenish-blue shale bed is apparently interbedded in places. This ridge of conglomerate lies half a mile a little west of south of Butts Hill, and, like the shales of that hill, is

believed to occupy the axis of the syncline. If that be true, the following exposures may be of interest, since they lie east of the sandstones and conglomerates which are nearer the western Newport road.

A number of exposures of coarse quartzitic conglomerate lie a quarter of a mile directly south of the ridge, and south of an east-west road. Their strike seems to be north-south.

Three-quarters of a mile southward, in the Portsmouth camp-meeting grounds, coarse conglomerate is exposed, interbedded with sandstone. Strike N. 7° W., dip 70° W. This exposure seems to lie on the eastern side of the syncline.

Southward no more coarse conglomerate is exposed. The next exposure lies a mile southward, south of the next east-west road, on the west side of the hill. Near the base of the hill occurs bluish-green sandstone with narrow streaks of pebble layers, the pebbles being of very small size. Farther east bluish-green shale is exposed at several points. This shale resembles the greenish shales described as occurring beneath the sandstones and conglomerates on the west side of the syncline. Their occurrence in the same position on the east side is significant. Strike north-south, dip low westward.

RELATIONS TO SLATE HILL SHALES.

It will be seen that the structure of the northern third of Aquidneck Island is that of a syncline, the great mass of the rocks being dark carbonaceous shales, and to a less degree sandstones. Overlying these, near the top, is a thin series of greenish shales, and a remnant of a conglomerate series overlying the green shales is still preserved in places near the middle of the syncline. A little over two miles south of the green shales above described, from the east and west sides of the syncline, the green shales of Slate Hill begin. The synclinal structure is no longer apparent so far southward. Instead of the single syncline of the northern third of Aquidneck the southern third shows at least three synclines—one east along the Sakonnet shore; a second, the southward-plunging syncline in the Paradise Rock series and west of Eastons Point; a third, just west of Miantonomy Hill and in the Coasters Harbor Island region.

Possibly the green shales near the top of Slate Hill represent the place where the marked southward pitch of these more southern synclines

begins. It is in the latitude of the Slate Hill sections, and thence eastward and westward to the shore on either side of Aquidneck Island, that it is most difficult to secure evidence of marked strikes and dips, a character often attending shaly rocks not steeply inclined, since the cleavage then most readily obscures the stratification, not departing far from its plane.

CHAPTER VII.

THE KINGSTOWN SERIES.

Unity and lithological character of the Kingstown sandstone series.—At the present stage of investigation it does not seem feasible to separate the Carboniferous strata lying along the western border of Narragansett Bay, between East Greenwich and Narragansett Pier, into divisions of geological value. No fossils have so far been discovered in them. Lithologically they consist of frequent alternations of the following rocks:

First. A coarse quartzitic sandstone, almost an arkose, evidently derived in large part from some earlier granite area. This sandstone frequently contains flakes of white mica, or of biotite and some other dark mineral. The color of the sandstone in general is white, the quartzitic elements very much predominating.

Second. As this sandstone becomes coarser it contains, at first, scattered quartzite pebbles, and then thin layers of a conglomeratic nature, merging into true conglomerates a few feet in thickness, the pebbles of which usually consist of quartzite, occasionally of granite, and, except in a few localities, do not exceed an inch or one inch and a half in diameter.

Third. As this sandstone becomes finer it also turns darker, the variation in color being usually due to an increase in the amount of carbonaceous material. In some of the more northern localities, however, the coarser and medium-grained sandstones are of a bluish color, which appears to be due to a decrease in the quantity of carbonaceous matter, making more evident the dissemination of iron in some form throughout the rock. The blue color is usually, in the case of the less carbonaceous sandstones, a sign of less metamorphism. During metamorphism the ferruginous matter seems to have collected partly in the form of magnetite and partly as a constituent of black mica, leaving the general mass of the rock whitish, but flecked with black specks.

Fourth. The medium-grained sandstones merge into a very fine-grained

and always very dark or black rock, the color being due to its carbonaceous character. It is difficult to determine whether to call this rock a fine-grained sandstone or a gritty shale, since it is sometimes massive and without cleavage and sometimes shaly.

Fifth. This merges into shale, the structure being due to cleavage. The micaceous elements of the sandstones here become very abundant. Sericite is a common constituent; the color at a distance often appears rather dark, almost black, especially where moistened by water; but at closer range it usually shows a dark-blue color, the dark tint being evidently due to the presence of ferruginous and carbonaceous matter.

Sixth. Occasionally the dark-blue shale becomes black, contains much carbonaceous matter, and is comparable with the coaly shales of the less metamorphosed part of the basin.

The types of rocks described above alternate in an irregular manner, making it impossible at the present to treat of them otherwise than as a geological unit. From Hazzard's quarry, a mile north of Saunderstown, to the angle of the shore a third of a mile south of Watsons Pier, the exposures are almost continuous. Here it is seen that the shales are an important part of the Carboniferous section on the western side of the bay, forming from a third to a half of the total thickness of the rocks exposed. The fine-grained sandstones are another important element. The coarse sandstones, although a conspicuous feature farther inland, can here hardly form a fourth of the total section.

Away from the coast, westward and northward, the exposures consist chiefly of sandstone, often coarse and conglomeratic. Finer sandstones also occur, but shales are rather infrequent, excepting in the regions (1) immediately south of Wickford, (2) a mile south of Sandy Point, on Potowomut Neck, and (3) a mile and a half directly south of the second locality. This diminution in the relative amount of shale exposed toward the west is striking, and would appear to indicate a corresponding lithological distinction between the shore exposures and the more inland part of the Carboniferous series toward the west and north were it not for the probability that the more isolated inland exposures represent chiefly the harder, less eroded, and therefore at present more elevated beds of the Carboniferous series, while the softer and less enduring rocks, including the finer sandstones and especially the shales, exist in considerable thickness

in any fully exposed section, but suffered more from weathering and now lie hidden under the more recent glacial and sand-plain deposits, leaving the coarser sandstones to form almost the only exposures rising above the sand-plain level. For this reason it is not safe to make any distinction between a more shaly and a less shaly series on the western shore of the bay. On the contrary, it is very likely that shales also form an important element of the series northward and westward, away from the shore line, but that, on account of their more ready erosion, they do not frequently appear above the soil.

On account of the far greater abundance of sandstones among the rocks of this western area, so typically developed in South and North Kingstown, than in the Aquidneck shales farther east, the name *Kingstown sandstones* is suggested for this western complex of strata, as being of value in designating them when it is desirable to distinguish the two formations where they are typically developed. The Kingstown sandstones underlie the Aquidneck shales.

Section from the Bonnet to Boston Neck.—At the Bonnet the Kingstown series dips about 60° E., giving an exposed thickness of about 700 feet, with a possible thickness of about 1,350 feet, if we include the area as far west as Wesquage Pond, which area, although without exposures, may be presumed to be underlain by similar rocks. Judging by the strikes along the shore, the lowest part of this section, consisting of the strata supposed to underlie the eastern edge of Wesquage Pond, can lie only a short distance above the most eastern exposures on Boston Neck and at the South Ferry. The most eastern exposures on Boston Neck dip nearly vertically; southeast of Watsons Pier the rocks dip 60° E.; west of the pier they dip 45° E.; three-quarters of a mile northward, 15° E.; these exposures, with the intermediate territory, add approximately 800 feet to the section already given, and make a total of 2,150 feet for the thickness of the Carboniferous section from the Bonnet southward, assuming that no folding has taken place.

Section from the Bonnet to Hazzard's quarry and Indian Corner.—The strata exposed along the shore of Boston Neck are probably repeated north of South Ferry, but the dips here are low, between 20° and 40° E., at times nearly horizontal, so that until much more accurate field work is done the strata north and south of the Bonnet can not be strictly compared with one another. The Bonnet section as far west as Wesquage Pond was estimated at 1,350

feet. The sections from South Ferry to the exposures nearest Saunderstown can, on account of these low dips, be estimated at about 350 feet, making a thickness of 1,700 feet from the eastern part of the Bonnet to Saunderstown. As the strata along the shore approach Saunderstown from the south, the dip along the strike increases, until north of Saunderstown it becomes nearly vertical. Then the dips, continuing along the strike, become 35° and 45° E., but in the section across Hazzard's quarry (Pl. XXI) and westward to the top of Barbers Height the prevailing dip varies between 50° and 65° E., adding about 2,200 feet to the 1,700 feet already accounted for, making a total of 3,900 feet for the section between the eastern part of the Bonnet and Barbers Height. To this must be added at least 1,600 feet more, in order to include the exposures south of the road nearly half a mile west from the top of Barbers Height, making a total section of 5,500 feet for the thickness of the Carboniferous from the Bonnet to the locality just mentioned. Making allowance for the change in the strike of the rocks toward the west of north, on going northward, a thickness of at least 3,600 feet must be added, in order to include both the exposures at Indian Corner and those at the locality half a mile south of the corner, east of the road, so that an estimate of 9,100 feet for that part of the Saunderstown sandstone series exposed on the western shore of the bay would be very moderate if the strikes and dips of the scattered exposures were considered as fairly representing the general structure of the strata beneath the soil. This estimate seems excessive, and a series of close synclines and anticlines, or of faults, may be imagined in order to reduce it to more moderate dimensions. It should, however, be remembered that at present no facts are known in this part of the field warranting such an interpretation of the structures actually observed. For a continuation of the discussion of the thickness of the Kingstown series in the southwestern part of the Narragansett Bay area, see page 336.

Kingstown series in southwestern Cranston and western Warwick.—At the present stage of inquiry it does not appear safe to make many statements as regards the equivalency of the Kingstown group north of East Greenwich to rocks exposed in the southern part of the field. The coarse conglomeratic sandstone at Hills Grove may belong to the Saunderstown series. The medium-grained sandstone east of Hills Grove and southwest of Norwood, with its bluish-gray color, is very similar to some of the sandstones exposed

SANDSTONE-GNEISS OF KINGSTOWN SERIES, DEVILS FOOT LEDGE, KINGSTOWN, RHODE ISLAND

along the road 1 and 2 miles north of Wickford. If the escarpment west of the railroad from Wickford Junction to East Greenwich, Coweset, Apponaug, Natick, and northward, marks the western boundary of the Carboniferous basin, south as well as north of East Greenwich, the equivalents of the Saunderstown sandstones must lie immediately east of that escarpment in Cranston and Warwick, and would be expected to show a considerable thickness and some lithological resemblance to the exposures southward. As a matter of fact, however, the exposures in Warwick are altogether insufficient to afford the basis for a judgment on this point. In southwestern Cranston, north of Natick and Pontiac, sandstones occur dipping at a low angle to the eastward, except along the Carboniferous margin. Beginning, however, near the State almshouse and extending thence northward along the east side of the hill occupied in part by the Reform School is a series of black shales, becoming in places very coaly. These coaly shales are the conspicuous feature of the Carboniferous section in western Cranston, and appear in the mines east of the Sockanosset Reservoir and on the east side of Rocky Hill. Beneath the coal-bearing shales at Sockanosset Hill are others of dark-blue or black color, often ottrelitic, which are exposed in the vicinity of Sockanosset Reservoir and near Wayland Station. Associated with these shales are sandstones, but these more northern sandstones are usually bluish gray, or more or less carbonaceous and medium grained, and, although not very different from the sandstones farther southward, do not closely resemble them

While, therefore, it seems beyond question that the rocks of western Warwick and Cranston form the northern extension of the Kingstown series, they present somewhat different lithological features, the shales being much more coaly, and at one horizon containing workable coal; moreover, the sandstones are finer grained and apparently less quartzitic and less suggestive of arkose. Still, while the more carbonaceous character of the shale northward is recognized, the abundance of dark-blue shales, certainly containing carbonaceous material, along the shore southward from Barbers Height to the Bonnet should not be forgotten. The more northern exposures, in Cranston, will therefore be regarded as simply a more carbonaceous phase of the Saunderstown series, while they evidently correspond also to the lowest part of the lower part of the Tenmile River beds or the Pawtucket shales of Mr. Woodworth.

Probable thickness of the Kingstown sandstone series in Cranston and Warwick.—The dips of the rocks exposed in southwestern Cranston are rather low, usually varying from nearly horizontal to 25° NE. and E. The miners report a steeper dip in the mine on the east side of Sockanosset Hill, the reported inclination being about 50° E.; but this, judging from surface exposures, seems to be but a local increase of dip.

On the eastern side of Warwick Neck, toward Rocky Point, the sandstones forming the slopes of the hill dip about 45° E. The first sandstones and shales met on the road to Rocky Point, and some of the sandstone and conglomerate exposures at the point also, slope about 20° E. Between Hills Grove and Norwood Station and Warwick Neck there are no exposures. Under these circumstances it is not safe to make calculations as to total thickness of the series of strata underlying Warwick and Cranston; but with an average inclination of 20° E., which is hardly warranted, considering the often lower dips where the rocks are actually exposed, the total thickness of the Carboniferous series from southwestern Cranston to the conglomerates of Rocky Point would be about 11,200 feet. The actual exposures suggest that this estimated thickness is perhaps extravagant. (See pp. 334, 337.)

If a series of close synclines and anticlines be imagined along the western margin of the southern part of the bay, extending northward into Warwick and Cranston, the preceding estimate can hardly be said to have any value whatever. In that portion of the field investigated by the writer, limited to the Narragansett Bay quadrangle, there is no actual field evidence of such folding, either north or south, although the great east-west extension of the Kingstown area of exposure is suggestive of such folding.

Warwick Neck exposures.—The lowest part of this thickness of 11,200 feet of Carboniferous strata in Warwick and Cranston is equivalent to the Kingstown series as exposed farther southward. Whether the Warwick Neck exposures belong to the Kingstown series can not be determined by the evidence secured in the area in question. Near the southern end of Warwick Neck carbonaceous shales occur along the shore, the contortion suggesting local folding. Black shales are found in the railway cut at the lower end of the neck. Heavy sandstone beds, some medium conglomerate layers, and dark-blue shales are seen on the eastern side of the neck, with more bluish shale on the east before reaching the conglomerate series of Rocky Point.

Lithologically the Warwick Neck exposures could be readily associated with the northern extension of the Kingstown series as exposed in southwestern Cranston, and might therefore be considered as forming part of the same series. They would constitute in that case the upper portion of the Kingstown series in the northwestern part of the Narragansett Bay area. This would make the Warwick Neck and Rocky Point exposures roughly equivalent to the more eastern exposures mentioned in the following paragraphs.

Exposures on the western islands of the bay.—The Kingstown series appears to be not limited to the western shores of the bay. The strata exposed on (1) Dutch Island, at (2) Beaver Head on Conanicut Island, toward the south of Dutch Island, (3) north of Round Swamp on the northern half of the island, (4) on Hope Island, and (5) along the western shore of Prudence Island, north of the wharves, all seem to belong to this series.

Thickness of strata between the Bonnet and Dutch Island.—The nearest point of approach of the island exposures with those on the west shore is between Dutch Island and Saunderstown, where they are distant 4,200 feet. Beaver Head is about 5,400 feet from South Ferry, and the most western part of northern Conanicut is 6,000 feet distant from the Hazzard quarry region north of Saunderstown. While, therefore, it may appear rash to associate in one geological series strata so far disconnected, other facts make this relation more than probable. Tracing the rocks of the Bonnet section northward on the map, in accordance with the suggestions offered by the actual strikes of the rocks exposed along the shore, it will be seen that the northward extension of the Bonnet series must lie a considerable distance toward the east of Saunderstown, while the southern extension of the Dutch Island strata would approach the western shore at the Bonnet. Traced in this way the Bonnet section is found to approach the Dutch Island section within 1,350 to 1,750 feet. Assuming a dip of 60° for this unexposed part of the section, the Bonnet section underlies the Dutch Island section from 1,200 to 1,500 feet. The dips, however, on the Saunderstown shore opposite the island do not exceed 40°, while the western shore dips of Dutch Island are also usually less than 50°, so that the two sections may possibly approach each other within 975 to 1,200 feet. Considering this moderate interval of unknown strata, and the absence of any signs to the contrary, the lithological simi-

larity of the Dutch Island rocks and the Kingstown sandstone series may be regarded as conclusive of their close geological relationship.

The Dutch Island exposures must therefore be added to the sections exposed on the mainland in order to form an estimate of the total thickness of th Kingstown series in the southwestern part of the Narragansett Bay region. This is discussed more fully in the third paragraph following.

Lithology of the Dutch Island series.—In general, the strata of Dutch Island may be described as consisting chiefly of sandstones with subsidiary conglomerate layers, underlain on the western side of the island by a series in which black, often very carbonaceous, shales predominate. Considering the black color of some of the Bonnet shales, the Carbonaceous character of the fern-bearing shales on Dutch Island is not unexpected. The conglomerate layers evidently contain larger pebbles than most of the conglomerates found high up in the series on the western side of the bay, but it is evident that their length is largely due to stretching. The pebbles are also less quartzitic than lower down. But it is the considerable abundance of sandstones in the Dutch Island section that suggests relationship with the Kingstown series.

Beaver Head section.—At Beaver Head, conglomerate is exposed only on the western border of the hill, near low-water mark. The main mass of the hill is evidently composed of black shales, with intercalated subsidiary thin sandstone beds and some arkose. The shales are decidedly carbonaceous. The Beaver Head section is evidently an introduction to the Aquidneck shale series as exposed farther eastward on the island, and seems to have its likeness in the carbonaceous shales at the base of the shale series on the western side of Prudence Island.

Total thickness of the Kingstown series, including the conglomerate at Beaver Head.—Taking 40° as an average of the eastward dips on Dutch Island, the thickness of the Dutch Island section is about 1,050 feet; this, added to the unknown interval of 975 to 1,200 feet occupied by the western passage (see bottom of preceding page) and the estimated thickness of 9,100 feet for the series as exposed on the western shores of the bay from the Bonnet to Hazzard's quarry, Indian Corner, and southward (see pp. 333 and 334), would give a thickness of from 11,125 to 11,350 feet for the whole series of Kingstown sandstones, including Dutch Island. An additional thickness of 225 feet would probably include the conglomerate layers exposed at low tide on the western margin of Beaver Head, so that 11,500 feet would express, in round

numbers, the total thickness of the Kingstown series in the southwestern part of the Narragansett Bay area. It will be remembered that in the northwestern part of this area, in Warwick and Cranston, the estimated thickness was 11,200 feet (see p. 336).

Western shore of Conanicut.—The rocks along the western shore of Conanicut also bear considerable resemblance to the Kingstown series as exposed on the mainland, owing to the presence of abundant sandstones, but they are still more similar to the strata exposed on Dutch Island, of which they are probably the continuation. Along the shore opposite Slocum and Great ledges there is considerable coaly shale, some of which, according to T. N. Dale,[1] contains fern impressions. There is also an abundance of sandstone, interbedded with which are subsidiary conglomerate layers with very much elongated pebbles, bearing considerable resemblance lithologically to the conglomerate of Dutch Island and the layer on the western margin of Beaver Head. The strikes along these ledges practically follow the shore. From Sand Point northward similar coaly shales and sandstones with subsidiary conglomerate layers are exposed. The strike is nearly N. 3° E. Along the entire western shore the dips are eastward, usually, however, quite low.

Eastern shore of Conanicut.—While the exposures along the western shore of northern Conanicut can be safely correlated with the strata on Dutch Island and western Beaver Head, the position and geological structure of the strata forming the middle and eastern parts of Conanicut remain, to say the least, problematical. East of North Point occur coaly shales, apparently showing lateral squeezing from east to west. Along the eastern shore are found coaly shales, at one point with fern impressions; also gray sandstones. The strikes average N. 10° E., and the dip is usually very steep, nearly vertical, but shows in places sudden variations which can most readily be reconciled with crumpling. The cleavage often obscures the bedding. The absence of conglomerate layers along the eastern shore is a conspicuous feature in contrast with the more western line of exposures, including western Conanicut, Dutch Island, and Beaver Head. The exposures along the eastern shore of northern Conanicut may therefore belong to another horizon, possibly a higher one corresponding to the strata overlying the conglomerates on the western margin of both Beaver Head and Prudence Island.

[1] On metamorphism in the Rhode Island coal basin: Proc. Newport Nat. Hist. Soc., Doc. 3, 1885, pp. 85–66.

Probable folding in the northern part of Conanicut Island.—The difficulties of the problem may be briefly stated as follows: The green shales of the southern half of Conanicut make their first appearance at the southern end of the lagoon east of Beaver Head. From this point they extend in a direction N. 37° E. to the eastern shore of the island, being last seen at a point a mile north of Freebodys Hill. The highest layer of conglomerate at Beaver Head occurs a little above low-water mark on the extreme western shore of the headland. The next most eastern exposure of conglomerate northward lies along the most western part of the shore of Conanicut, northwest of Round Swamp. The second locality lies about N. 10° E. from the first. The average strike of the sandstones, coaly shales, and conglomerate beds on the western side of northern Conanicut is not more than N. 10° E., which seems to suggest a connection between the Beaver Head conglomerate and the conglomerates farther northward. In that case, however, there is a divergence of about 27° between the conglomerate layers on the west and the green shales on the east, which suggests a thickening of the intervening strata northward, an unconformity, a peculiar form of fan-shaped folding, or a fault. There is, however, no good geological evidence for any one of these suggestions.

Curiously enough, the strikes on the eastern side of Conanicut, north of the latitude of southern Gould Island, are also N. 10° E. This makes it difficult to imagine the precise nature of a system of folding which would give such an increase of area in an east-west direction northward as has been just described, and which nevertheless could escape detection in the regions where actual exposures occur. The strata on the western shore of northern Conanicut dip eastward at a low angle. On the eastern shore, north of the latitude of southern Gould Island, the dips appear very variable, being sometimes almost vertical. These steep dips may be an expression of that folding which must also obtain over the middle length of the island, in order to reconcile the apparent divergence of the conglomerate layers and the green shales as described above, without recognizing a marked increase in the thickness of the strata involved or any possibility of faulting or of an unconformity. The facts observed elsewhere in the field do not warrant the assumption of a great unconformity here, but the possibility of faulting must not be precluded.

If the possibility of a fault starting somewhere northeast of Beaver

Head and increasing toward Round Swamp and beyond be excluded, a low general eastward dip of a series of strata, subjected to abundant subsidiary folding, pitching southeastward along their southern border, is the only explanation that occurs to the writer, and very much more field work is necessary to form anything like a safe opinion on this point. In the absence of more accurate information an estimate of the maximum thickness of the strata involved in the northern Conanicut complex seems unwarranted. The thickness certainly amounts to as much as 1,735 feet, but it may many times exceed this.

Hope Island.—Lithologically the rocks forming Hope Island resemble the strata exposed on the western shore of the bay more closely than the more northern exposures along the western side of northern Conanicut. This may be due in part to the greater metamorphism of the Hope Island rocks. The sandstone here is often quartzitic, of white color, and contains biotitic mica. The interbedded fine-grained sandstones are usually very black. Black shales are found only along the western and northern sides of the island, and form evidently the lower beds of the small section here involved. The quartzitic sandstones contain scattered pebbles and thin conglomeratic layers. Conglomerates are present to a certain degree in all the sandstone layers. On the western side of the island they are a minor feature, while on the eastern side they form half the rock. The pebbles are uniformly small, usually not over 1½ inches in diameter. Many of them are decidedly quartzitic or granitic. There has been little flattening of the pebbles by shearing. The strike over the southern three-fourths of the island averages N. 30° E., with an easterly dip of 60° to 80° on the western side, and a dip of 30° to 45° E. on the eastern shore. These strikes also suggest that the Hope Island section may underlie the exposures on the western shore of northern Conanicut, notwithstanding the northerly strikes of the latter. The section exposed on the island is estimated to have a thickness of at least 800 feet.

At the northern end of Hope Island the dip of the strata is very low to the northeastward. Were it not for this fact the more southern strikes would carry these strata approximately toward Pine Hill and Gull points, on northern Prudence Island. The outlines of the coast and the trends of the main hills on northern Prudence Island and on Patience Island suggest

a strike toward the west of north for the underlying strata, which would agree with the exposures at Rocky Point.

Kingstown series exposures on the western islands.—From the Bonnet the Kingstown series has been traced northward into western Warwick and southwestern Cranston. The relationship of the overlying Dutch Island section has been shown, and similar rocks have been traced along the western part of northern Conanicut, and others form Hope Island. The exposures at Beaver Head and along the eastern shore of northern Conanicut appear to be a more coaly variation, intermediate between the sandstone series beneath and the green and dark-blue shales above.

Prudence Island.—Lithologically somewhat similar features are presented along the western side of Prudence Island, where sandstones and some conglomerate occur along the shore north of Prudence Park wharf, dipping eastward, on the average, about 25°. Overlying these are black carbonaceous shales and sandstones containing fern leaves. Higher, near the wharf, are shown the dark-blue shales. If the dark-blue shales be correlated with the green and dark-blue shales of Conanicut, and if the sandstones and conglomerates be associated with the Kingstown series as shown on Dutch Island, then the coaly shales are equivalent to the black shales forming the main mass of Beaver Head. Comparisons at so great distances have, of course, little value. The real reason for considering the sandstones and conglomerates of the western shore of Prudence Island as equivalent to the top of the Saunderstown series is their situation beneath a considerable thickness of shales. The thickness and lithological characteristics of these shales seem to warrant their correlation with the great body of shales on Aquidneck Island and the southern part of Conanicut Island, the whole forming a geological group in the bay region of the Narragansett Basin, which group is here called the Aquidneck series, and which overlies the Kingstown series. The unity of the shale series will be discussed further on. Correlating the conglomerates on the western shore of Prudence Island with the conglomerate at Beaver Head, it may be suggested that the sections at Rocky Point may not far underlie their horizon.

The actual exposure of sandstones and conglomerates north of the wharf at Prudence Park can hardly exceed 50 feet. The overlying coaly shales may possibly amount to 150 feet in thickness south of Prudence Park wharf, but if that is the case they certainly thin out rapidly north-

ward, since the more northern exposures on the island show that the sandstones and conglomerates are overlain by the dark-bluish shale, with only a small interval of unknown rock. The most ready interpretation of this fact is to suppose that the lower part of the Aquidneck shales is often coaly, the thickness of this coaly section, however, being greatly variable.

Western Bristol Neck.—Bluish and greenish Aquidneck shales form the main mass of the Carboniferous rocks on Bristol Neck. Underlying them on the southwest is a thick bed of sandstone, amounting to perhaps 50 feet. About 225 feet beneath this bed occurs more sandstone, of dark color, containing coaly matter, and perhaps 150 feet beneath this level is coaly shale with fern-leaf and Annularia impressions. If the eastward dip of 20° is maintained, the conglomerate exposed at two localities above the main sandstone bed first mentioned lies about 250 feet above the latter. A short distance above the conglomerate begin the greenish and dark-blue shales of the Aquidneck series. The order of succession on the western side of Bristol Neck is, therefore: coaly shale, gray or darker sandstone, bluish sandstone, conglomerate with large pebbles, greenish and dark-blue shales. If the great shale series of Bristol Neck be correlated with the shales of Prudence Island and southern Conanicut, the underlying rocks may represent the upper part of the Kingstown series. Certain facts suggest a relationship with at least the Prudence Island section. Pebbles containing oboli are found in the conglomerate on the west side of Prudence Island. While the pebbles of the conglomerate on the west side of Bristol Neck are of much larger size, their lithological character agrees very well with that of the Prudence Island pebbles, and oboli will no doubt be eventually found there also. There is a considerable section of sandstone on the west side of Bristol Neck. It is not interbedded with the conglomerate, but is found beneath it. The coaly shale on Bristol Neck, as well as that on Prudence Island, contains plants, but the coaly shale on Bristol Neck occurs, not at the base of the greenish and dark-blue shales, but below the sandstones and conglomerates of that field. As a matter of fact, however, these latter belong very high in the Kingstown series, and strict parallelism of strata could hardly be expected at so great a distance as that from Prudence Park to western Bristol Neck, in a geological field where lithological changes along the strike are frequent. Only a general accordance could be demanded. For this reason the coaly shales,

sandstones, and conglomerate of western Bristol Neck are considered as belonging at the top of the Kingstown series. The sandstone exposures on Popasquash Neck probably belong to the same horizon.

Rumstick Neck.—The green shales of Rumstick Neck resemble the green shales of western Bristol Neck and some of those of Prudence Island. The sandstone underlying the same, offshore toward the southwest, contains plant-stem impressions similar to those found in the sandstones beneath the shales on the western side of Prudence Island The curve of the strike of the sandstones suggests a shallow syncline pitching northward, and a similar curve in the strike of the chief sandstone bed on the southwest side of Bristol Neck suggests a similar structure there. The exposure on Rumstick Neck is, however, too isolated to be safely correlated.

Kingstown sandstones equivalent to the lower part of the Coal Measures group.—If the strikes of the coaly shales, the sandstones, and the conglomerates on the western side of Bristol Neck be continued for any considerable distance northward, rocks referred by Mr. Woodworth to the Seekonk section will be met. The Kingstown series would therefore seem to correspond to the lower part of the Coal Measures, including the Seekonk group, as limited by Mr. Woodworth farther northward.

Triangular area of the Kingstown series in the Narragansett Basin, narrowing southward.—Provided that all the correlations so far made are correct, the following fact is brought out. In the latitude of the Bonnet the Kingstown series occupies a width of $3\frac{3}{4}$ miles. The eastern margin of the area occupied turns northeastward at Beaver Head, with a direction of N. 38° E., as far as the eastern side of Conanicut. At the latitude of Hammond Hill the series occupies a width of at least 5 miles. At Hammond Hill the western margin of the area turns northwestward, and in the neighborhood of Wickford Junction the width of the area is about $8\frac{1}{4}$ miles. According to this measurement the eastern border of the area takes a more northerly course along the east side of northern Conanicut. From Wickford Junction the western border extends N. 23° E. to East Greenwich, and the eastern border N. 24° E. along western Prudence Island to the eastern side of Popasquash Neck. The width of the Kingstown area at East Greenwich, according to this, is 8 miles. North of Coweset the western margin extends in a northwestern direction as far as southern Cranston, and thence N. 10° E. The eastern margin may extend northward along the western side of Warren

River. In that case the area involved has a width of at least 10 miles at the northern limit of the Narragansett Bay map.

The increase in the width of the area occupied by the Kingstown series from 3¾ miles on the south to 10 miles on the north is of course striking and demands some explanation.

Thickness of the series and evidence of folding.—The thickness of the series can be measured with the greatest degree of certainty at its southern end, where exposures are frequent and dips are steep. The total thickness of 11,500 feet there indicated may not equal that of the formation farther northward. The steep dips in the area immediately north of a line connecting Quonset Point, Wickford, and Wickford Junction, for instance, suggest a greater thickness. So does the great east-west extension of the formation northward. Unless in spite of the apparent uniformity of strikes and dips over large areas there be in reality a system of repetition due to folding, the thickness of the Kingstown sandstone group must in places greatly exceed 11,500 feet. There is a little evidence in favor of such folding in the portion of this region actually occupied by the Kingstown sandstones: (1) Along the eastern side of Providence River, north of Riverside occurs a synclinal fold, but this seems to disappear northward. (2) At Rumstick Neck and on the southwestern side of the Aquidneck shale area on Bristol Neck the trend of the underlying sandstones suggests synclinal folding. (3) Prudence Island is a case of a well-marked synclinal fold. (4) The steep dips, varying suddenly to lower inclinations, on the northwestern side of Conanicut suggest crumpling of strata and possible folding. (5) The shale area of southern Conanicut has evidently suffered folding, but the character of this folding has not been well worked out. (6) Folds are known in various parts of Aquidneck Island All of these facts suggest folding also in the more western area occupied by the Kingstown sandstones, but the direct evidence in favor of such folding is still wanting.

The view that the thickness of the sandstone series northward probably does not greatly exceed 11,500 feet is also supported by the very low general inclination of the strata over considerable areas, which tends to reduce the estimates made in conformity with regions where the dip is steeper. The very low general dips of most of southwestern Cranston and Warwick have already been mentioned.

The dips on the western side of Bristol Neck are comparatively low.

This is also true of the inclination of the strata on the western side of Prudence Island and on the western side of Conanicut. The shale series east of Mackerel Cove and on Freebodys Hill seems also to have low dips. North of Barbers Height, toward Hamilton and northwestward, the dips also become lower, indicating a greater horizontal extension of the series for the same thickness of strata than exists farther southward. The evidence on Potowomut Neck is in favor of low dips.

If these areas of low dips among those of higher dips can be considered as evidences in favor of a system of local folding, at present only obscurely known, it will not be necessary to assign any extravagant thickness to the more northern portion of the Saunderstown series.

Rocky Point conglomerate and its connection with the estimate of the thickness of the northern section.—Unfortunately, the estimate of 11,200 feet for the Kingstown series in southwestern Cranston and in Warwick does not offer a means of comparison with the more southern section noted above, because (1) it does not include the Rocky Point conglomerates, supposing that the latter lie at the top of the Kingstown sandstone series, and (2) it is not determinable that the rocks immediately beneath the Rocky Point conglomerates belong to the sandstone series, for the reason that the age of the Rocky Point conglomerate is not known with certainty. In the field investigated by the writer there is no evidence militating against the belief that these conglomerates correspond to those which begin to occur near the top of the Aquidneck shales as exposed northeast of Warren, and which are there an introduction to the Dighton conglomerates. In the area north of that investigated by the writer, the Rocky Point conglomerates, or rather their supposed equivalents, seem to occur at a horizon corresponding more nearly to the top of the Kingstown sandstone series, similar to the conglomerate of western Bristol Neck and western Prudence Island. This is equivalent to placing them on the horizon of the Seekonk group of Mr. Woodworth, which includes also the series of shales, sandstones, and medium conglomerates into which the Aquidneck shales merge north of Warren.

Chief features of the Kingstown series.—The Kingstown sandstone series may be described as a complex consisting of alternations of shale, sandstone, and conglomerates. The conglomerates are usually made up of very small pebbles. Near the base of the section, however, in the basal arkoses and associated rocks there occur layers with large pebbles. Toward the top of

the section conglomerates come in again. These are seen at the western margin of Beaver Head, on Dutch Island, the western side of northern Conanicut, the western side of Prudence Island, and the western side of Bristol Neck; and apparently the conglomerates at Rocky Point and the eastern side of Providence River belong at this horizon. (See the paragraph on the equivalence of the Kingstown and Aquidneck series, on p. 361.)

Fossil-plant localities.—Coaly shales with fern impressions occur as follows: About 2,000 feet above the base of the series are the coaly shales of Sockanosset Hill, inclosing fern leaves. At the top of the series and at several points farther down are more carbonaceous shales, also containing fern impressions. The highest beds with plant remains in the Kingstown series are the conglomerate and sandstone beds exposed on the western side of Prudence Island. The coaly shales just above belong to the base of the Aquidneck bed. On Beaver Head the shales in the upper part of the Kingstown series do not preserve the fern impressions. The fossil locality on the eastern side of northern Conanicut probably belongs a little above this horizon. A slightly lower horizon is occupied by the exposure of fern-bearing coaly shales on the west side of Bristol Neck. A still lower one includes the fossil-fern locality on the western side of Dutch Island and the locality discovered by Prof. T. Nelson Dale on the western side of northern Conanicut. A comparison of the ferns from the upper and lower horizons might show variations in the flora, giving suggestions as to means of recognizing the same horizons observed in the field.

Plant stems are found above the level of the lowest coal horizon at Hills Grove and near the top of the section on the western side of Prudence Island, and possibly the exposures off the end of Rumstick Neck and along Providence River, in all cases consisting of sandstones belonging to the same horizon. Indeed, the upper half of the Tenmile River section of Mr. Woodworth appears to be in places rich in calamites.

Ferns occur again in the overlying Aquidneck shale series and in the coaly shales interbedded with the coarse conglomerate series at the top of the Narragansett Basin Carboniferous section at Castle Hill, as will be described later, demonstrating that all of the exposures here described, from the basal conglomerates and arkoses to the top of the Purgatory conglomerate, are Carboniferous.

CHAPTER VIII.

THE AQUIDNECK SHALES.

AREA OCCUPIED BY THE AQUIDNECK SHALE SERIES.

East of the complex of rocks called the Kingstown sandstones, owing to the characteristic and frequent appearance of sandstone beds in the section, lies an equally great area, in which shales form almost all of the exposures, excepting where synclinal folding has allowed an overlying conglomerate to be locally preserved. The shales of this eastern area contain isolated sandstones and thin conglomerate beds, but the latter are so rare that the term "shale series" has peculiar force in designating the general lithological character of the rocks in question. The shales occupy (1) the southern half of Conanicut Island as far north as Round Swamp, excepting (a) the small area included in Fox Hill, already described as the top of the Kingstown section, and (b) a small area of arkose on the east side of Mackerel Bay, north of the granite hills. They form (2) the southern and larger division of Prudence Island (Pl. XXIII), excepting the western margin of the island, north of Prudence Park. They are frequently exposed (3) in almost all of Bristol Neck, north of the granite area, only the most western exposures on the neck belonging to the Kingstown series. The shales form also (4) almost the whole of Aquidneck Island, excepting (*a*) at the top of the syncline south of Butts Hill, and in those areas occurring along (*b*) the southeast shore of the island at Woods Castle, (*c*) in the Paradise-Purgatory region, (*d*) at the Newport Cliffs, (*e*) on Miantonomy Hill, and (*f*) at Coddington Point, where the overlying conglomerates prevail. The (*g*) pre-Carboniferous rocks of the Newport Neck region must also, of course, be excluded. Owing to the abundant exposures of the shales on Aquidneck Island and the belief that all these shales form one great series, the Aquidneck exposures are considered typical, and the shale series wherever exposed is therefore called the Aquidneck shale series.

SOUTHERN CONANICUT.

The shales on Conanicut form a singularly uniform series. Owing to abundant cleavage, they are everywhere strongly fissile, splitting into thin plates. The color is usually dark blue, appearing nearly black where moistened by water, and more brownish or greenish brown where very dry. But variations from greenish to nearly black occur also, entirely aside from any question of moisture, the darkening of color being due to the amount of carbonaceous material present. This gives rise to an alternation of darker and lighter color bands, which is very characteristic of the shales in many parts of Conanicut, and without which it would rarely be possible to determine the plane of stratification of the rock. Not a trace of conglomerate or of coarse sandstone has so far been found in the shale series of Conanicut. Thin layers of a very fine-grained whitish sandstone occur along the southern margin of Dutch Island Harbor, along the shore east of Fox Hill, and on the eastern shore along Freebodys Hill. Where there is no color-banding or whitish sandstone there is no means of learning the real dip and strike of the shales, the cleavage obscuring all traces of stratification. The dips on the western side of Conanicut are certainly, in places, very steep to the westward, practically vertical, but at the first exposure south of Fox Hill the dip is between 45° and 60° E., and this, in connection with the general eastward dip of the strata on Fox Hill, is one of the main reasons for believing that the Aquidneck shales overlie the Saunderstown sandstones.

On the eastern side of the western division of the island—i. e., along the western side of Mackerel Cove and thence southward—the dips are usually eastward at angles which are frequently as low as 45°, and sometimes much lower. On the eastern side of Mackerel Cove the dip is low to the east. On Freebodys Hill some of the dips are nearly horizontal, others are low to the east, and in places the dip is very variable. So little being known of the geological structure of the island, it is impossible to form a close estimate of the thickness of the shale series exposed there. A minimum estimate would be 2,000 feet, while 4,200 feet can not be called a maximum for the entire series, considering the steep dips on the western side of the island. The coaly shales on Fox Hill, at Beaver Head, may be considered as forming a transition series between the Kingstown sandstones beneath and the Aquidneck shales above.

PRUDENCE ISLAND.

In the case of the coaly shales on the western side of Prudence Island, it is equally probable that these shales indicate the beginning of the great Aquidneck shale series immediately overlying them. On the western side of Prudence Island the Aquidneck shales proper are of a dark-blue color, like those on Conanicut and Aquidneck islands. The few exposures above the sandstone series a mile north of Prudence Park suggest that sandstone layers are, however, a more common element in the shale series here than on Conanicut. The same observation also applies to the exposures south and southeast of Potters Hotel (which is located on the highest point of the island), where sandstones and even some thin conglomerate layers occur. Color banding is not seen on the western side of Prudence Island, but on the eastern side, about two-thirds of a mile north of the light-house on Sand Point, color-banded shales like those on Conanicut are well exposed (Pl. XXII). South of the light-house the shales are sericitic, and not so fissile, or at least usually not partially separated along the cleavage into thin plates, as they are elsewhere, yet it is evident that these shales of eastern Prudence Island could also be readily split parallel to the cleavage produced by the abundant presence of this micaceous mineral. An unusual feature is the frequent presence south of the light-house of sandy courses, from 8 to 12 and even 20 inches in thickness, some of which merge into thin conglomerate beds. One or two of the pebbly beds attain a thickness of 2 or 3 feet and constitute a genuine conglomerate. The color of the shale on this eastern side of Prudence Island is more inclined toward the greenish hue of the shales at Eastons Point than toward the dark blue so common on Conanicut Island. A few more carbonaceous shale layers occur intercalated among the greenish beds

The eastern Prudence Island exposures south of the light-house therefore present more frequent variations from the dark-blue color and fissile structure of the Aquidneck shales, and show more frequent sandstone and conglomeratic layers, than do these shales on southern Conanicut or southern Aquidneck. Sandstones and thin conglomerate beds are fairly frequent, however, on Aquidneck or Rhode Island, directly east of the Prudence Island exposures just described; also in the area from Coggeshall Point to McCurrys Point and thence northward to within half a mile of Butts Hill. These facts suggest an increase in the amount of sandstone, and even the

STRATIFICATION AND SLATY CLEAVAGE, AQUIDNECK SHALES. EASTERN SHORE OF PRUDENCE ISLAND. LOOKING NORTH

Strike N. 29° E.; dip, 75° W.; cleavage dipping 12° E

introduction of conglomerate, in the lower part of the Aquidneck shales on going northward.

THICKNESS OF THE SHALE SERIES ON EACH SIDE OF THE PRUDENCE ISLAND SYNCLINE.

The structure of Prudence Island is a syncline, the sides dipping 20° to 25° E. on the west side (Pl. XXIII), and 70° to 80° W. on the east side. The bottom of the syncline appears to be at Potters Hotel or to the westward. The thickness of shales forming the western side of the syncline as far as exposed may be 2,200 feet. The thickness included in the exposures forming the eastern side of the syncline appears with more certainty to be at least 1,750 feet. In that case the lower 450 feet exposed on the western side of the syncline may not be exposed on the eastern side of the island. Since these estimates are not based on a continuous series of exposures in an east-west direction, there being no exposures for almost a mile west of Potters Hotel, the figures given can not have great value, although they serve to give at least some notion as to the probable minimum thickness of the shale formation. The sandstones and conglomerates on the western side of Prudence Island north of the wharf being assigned to the Kingstown series, it is evident that the Aquidneck shale series as exposed on this side of the island overlies the Kingstown series. For this reason the western part of the Prudence Island section is believed to furnish evidence in favor of the more recent age of the Aquidneck shale as compared with the Kingstown sandstones. This corroborates the evidence furnished by the Beaver Head section on Conanicut.

BRISTOL NECK.

The greenish, dark-blue, and greenish-blue shales of Bristol Neck are known to dip low eastward on the western side of the neck. If the sandstone and conglomerate beneath the shales on the west belong to the Kingstown sandstones, the more recent age of the Aquidneck shales is here indicated once again. A sandstone layer, becoming conglomeratic near the Warren-Bristol road, occurs in the shale series about 400 feet above the coarse conglomerate layer at the supposed base of the shales, and thus shows the existence of occasional sandy and conglomeratic layers in the Aquidneck shale series northward. Sandstone layers are not known

to occur elsewhere in the Aquidneck shales of the neck. The dip of the stratification of the shales over the middle and eastern part of the neck can not be determined with certainty. Under these circumstances there is no sufficient evidence from which to estimate the thickness of the Aquidneck shales here exposed; 1,700 feet would appear to be a very moderate estimate; 2,700 feet may be excessive. The low dips of the sandstone and conglomerate on the western side of Bristol Neck, and the low dip of the coarse conglomerate on the western side of Warren Neck, taken in connection with the small east-west extent of the lines of exposure of the Aquidneck shale series, have caused the writer to believe that the shale series was not so thick on Bristol Neck as it is farther southward, and that probably the Aquidneck shales diminished in thickness in passing northward from southern Aquidneck Island into Bristol Neck.

AQUIDNECK ISLAND.

The Aquidneck shales are typically exposed (1) in the Glen and (2) in the valley south of McCurrys Point on the east side of Aquidneck, or the Island of Rhode Island; also (3) in the valley east of Coggeshall Point, (4) in Lawtons Valley, and (5) in various stream beds, railway cuts, and shore exposures as far south as Coddington Point and in the railroad cut west of Beacon Hill, both on the western side of the island. The Aquidneck shales form by far the greater part of the stratified rocks of the island. They are characteristically dark blue, and usually do not show color banding, which is also true of the Bristol Neck exposures. Thin fine-grained sandstone beds occur not only in the shale series northward, but also in the middle and southern part of Aquidneck, where the shale series is most typically developed, so that the Conanicut shales are at one extreme lithologically of the shale series, in presenting hardly any sandstone layers at all, none of those existing being even coarse, while the eastern Prudence Island and the northern Aquidneck exposures, just east of the Prudence Island exposures, are at the opposite extreme, containing more or less interbedded thin sandstone and some conglomerate layers. On Aquidneck Island thin medium-grained sandstone beds occur in the shales (1) at the north end of Coddington Neck and (2) along the main Newport-Bristol Ferry road a short distance south of Lawtons Valley. Coarse sandstone, merging in places into a very small-pebbled conglomerate, is found (3) east of the railroad

WAVE-CUT BENCH IN AQUIDNECK SHALES, WESTERN SHORE OF PRUDENCE ISLAND

About 1 mile south of wharf; looking south. Width of platform, from 15 to 20 feet. Stratification, schistosity, and cleavage nearly coincident. Strike, N. 9° E.; dip, 28° E.

half a mile south of Lawtons Valley, and a series of exposures containing sandstone extends (4) from the valley east of Coggeshall Point for at least half a mile northward. Sandstone layers are also exposed (5) along the middle third of the coast both on the east and on the west side of the island, and a bed is also located (6) in the lower part of the Glen valley. Sandstone occurs rather frequently in the shale series (7) for a mile south of Coggeshall Point, and both sandstone and small-pebbled conglomerate layers occur (8) along the eastern shore from McCurrys Point to the exposures east of Butts Hill.

THICKNESS OF THE SHALE SECTION EAST OF THE PORTSMOUTH SYNCLINE.

The geological structure of the shale area over the northern third of Aquidneck Island is evidently that of a syncline, the base of the syncline passing beneath Butts Hill and extending a little west of south toward the west of Quaker Hill. The dip on the eastern shore of the island varies between 20° and 40° W., and at the mine northeast of Butts Hill it is about 20° W. According to this the coal seam opened at the eastern coal mine could hardly be more than 500 or 570 feet above the shore exposures along the northern third of Aquidneck, while the coarse conglomerate south of Butts Hill, and elsewhere at the same level in the syncline, can hardly be more than 500 to 650 feet higher. According to this the shale section exposed on the east side of the syncline probably averages somewhere between 1,000 and 1,220 feet, but may be a little less than 1,000 feet in thickness, and might possibly exceed 1,300 feet.

PROBABLE THICKNESS OF THE SHALE SECTION WEST OF THE PORTSMOUTH SYNCLINE.

Along the shore north of Coggeshall Point the dip appears to be low to the east, usually not exceeding 20°. Farther east the dips are steeper to the east, varying most frequently between 45° and 60° E. According to this the coarse sandstone layer on the brow of the hill east of Coggeshall Point lies about 1,300 to 1,500 feet beneath the level of the coarse conglomerate; the shore exposures lie between 1,300 and 1,500 feet lower, and the western mine exposures occur apparently at a still lower level, perhaps 400 to 500 feet beneath. According to these estimates the western

coal beds lie between 3,000 and 3,500 feet beneath the coarse conglomerate, while the eastern bed lies between 500 and 570 feet beneath the conglomerate, so that eastern and western coal beds do not belong to the same horizon, but one underlies the other about 2,500 to 2,900 feet. It should be remembered, however, that these estimates are made without a knowledge of the results obtained by a series of diamond-drill borings made west of the eastern mine within recent years. The apparent failure to detect on the western side of the syncline the coal bed which was worked in the eastern mine also suggests either that the bed thins out westward or that it has so far not been discovered on that side of the syncline.

LITHOLOGICAL VARIATIONS IN THE SHALE SERIES.

The appearance of frequent sandstone beds and an occasional conglomerate layer on the eastern shore, east of the Portsmouth syncline, and the exposure of only one or two coarse sandstone beds on the western side of the syncline, on the brow of the hill east of Coggeshall Point and northward (according to preceding calculations approximately at the same level), suggests that there may be a reduction to the westward of the amount of sandy material at this particular horizon. In a general way also there appears to be more carbonaceous material in the shale series on the east side of the Island of Aquidneck than at corresponding heights westward, and there is certainly less carbonaceous material in the shale on Prudence Island and on Bristol Neck than eastward. Observations of this nature have little value, however, since the recorded strikes and dips are not sufficient in number to give assurance regarding the strike and dip of the intermediate localities, where exposures fail or where the stratification has been obscured by cleavage.

GEOLOGICAL STRUCTURE OF THE MIDDLE THIRD OF AQUIDNECK ISLAND.

From McCurrys Point to the exposures half a mile north of Black Point, little can be determined about the dip of the rocks. In the Glen a sandstone layer appears to be nearly horizontal. Nothing satisfactory could be determined about the dip of the exposures along the road from Slate Hill southwestward. North and south of Lawtons Valley, and at several

points along the western shore, the dip, however, is distinctly eastward. Over this more eastern part of the middle third of Aquidneck Island the strata are believed to be inclined at a low angle, and to form a series of low folds, leaving the rocks in general essentially horizontal. Along the western coast, however, and for a distance of a mile or more east of the same, more marked eastward dips occasionally occur, and here the folding may be more pronounced, although the recorded observations so far fail to give evidence of marked folding.

STRATA PROBABLY FOLDED.

If the coarse conglomerates of Coddington Point, Coasters Harbor Island, and Miantonomy Hill correspond to the coarse conglomerates in the northern third of the island, it is evident that, in spite of the eastward dips so far recorded from the western Portsmouth mine as far as Coddington Point, there must be some system of folding as yet not discovered, which (1) allows the Miantonomy Hill exposure of conglomerate to appear to the west of the line of strikes shown by the shales to the northward, while they are still evidently above the Aquidneck shales as exposed near the hill; (2) the fact that the Coasters Harbor Island and the Coddington Point exposures of coarse conglomerate lie at least 100 feet beneath those at Miantonomy Hill suggests that there must be folding between these localities, if the two sets of coarse conglomerates are to be considered as of the same age, and the exposures at Coasters Harbor Island and Miantonomy Hill favor that view.

The synclinal structure of the southern half of Prudence Island and the northern third of Aquidneck Island demands anticlinal structure in the region between. How far south either the anticline along the Eastern Passage or the syncline of Prudence Island extended is unknown. Are the coal beds in the western mines near the base of the Aquidneck shale series? Do these coals thin out westward? Are the coaly shales on the western shore of Prudence Island the representatives, in a general way, of the thicker coal beds at the Portsmouth mine? Do the coaly shales of Gould Island belong to the same horizon—i. e., that of the Portsmouth mine coal beds? These are questions which can not be satisfactorily answered in the present state of our knowledge.

GOULD ISLAND OF THE MIDDLE PASSAGE.

The strike of the strata composing Gould Island is generally north-south. Plumbago and coaly shales form almost all of the shore exposures on the eastern shore for a little more than half the length of the island, going southward. Farther south carbonaceous shales continue to appear, but sandstone, in part conglomeratic, also makes its appearance. The pebbles of the more conglomeratic layers are very small. The dips are chiefly east, but very irregular, and the most northern dip appears to be westward, while the strata about a fourth of the length of the island north of its southern end are nearly vertical.

SOUTHERN THIRD OF AQUIDNECK ISLAND.

South of the line connecting Coddington Point and Black Point, including the southern third of Aquidneck Island, the typical dark-blue and greenish-blue shales of the Aquidneck series are not often exposed (see footnote on page 372). The top of the series is exposed at Eastons Point, but presents features which it is desirable to discuss in connection with other exposures farther north that seem to belong to the same horizon. This will be done under the next heading.

UPPER GREEN SHALES OF THE AQUIDNECK SERIES.

The great mass of shales exposed on Aquidneck or Rhode Island undoubtedly constitute a single series. Considering their thickness and their considerable geographical distribution, they present decided lithological uniformity. Along the middle of Aquidneck Island, however, the upper part of the shale is greenish in color, in contrast to the chiefly dark-blue fissile shales underneath. These green shales are well exposed (1) for a mile along the western road from Newport to Bristol Ferry, southwest of Butts Hill, on the western side of the Portsmouth syncline. They are seen again (2) half a mile southwest of the top of Quaker Hill, on the eastern side of the syncline. The green shales include near the top more sandy layers and sandstones, followed higher up by the sandstones and conglomerates of the conglomerate series. At (3) Slate Hill and for over a mile southwestward along the road green shales are again exposed. The coarse conglomerate series which is supposed once to have overlain them is

no longer present, and if ever in existence here must have been removed by erosion. At (4) Eastons Point greenish shales verging to bluish are well exposed beneath the coarse conglomerate on both sides of the anticline. The greenish shales of all these localities are believed to represent the top of the great Aquidneck shale series. This does not mean that all of the greenish shales elsewhere also belong to this upper horizon. The greenish shale of the western part of Bristol Neck certainly belongs low in the shale series, and not at the top, but along the middle length of Aquidneck Island, from the Portsmouth syncline to Eastons Point, such a north-south line of green shales near the top of the Aquidneck shales can be recognized.

SAKONNET SANDSTONES OF THE AQUIDNECK SERIES WEST OF THE RIVER.

West of the line of upper green shales just described the corresponding upper layers of the Aquidneck shale series are not greenish in color, but show the more usual dark-blue tinge. This is certainly true beneath the Miantonomy Hill and Coddington Point conglomerates, where the underlying shales seem to represent the same horizon. Eastward of the line of upper green shales described there are other exposures of the upper shales of the Aquidneck series, which are also occasionally green in color—for instance, north of the conglomerate area at Fogland Point. But usually the more eastern exposures of the upper Aquidneck series fail to show a marked shaly character; on the contrary, they more frequently become more sandy in some of their layers, or even take on the general character of a sandstone series, in which shales form only the subsidiary beds. When this occurs, the finer sandstones usually contain considerable carbonaceous material. Such shales with a predominating amount of dark-gray or blackish sandstones are found at the top of the Aquidneck shale series and beneath the coarse conglomerates along the shore north of Black Point, and to a less pronounced degree at Taggarts Ferry. The more sandy character of the upper part of the Aquidneck series along the southeastern side of the island may indicate approach to shore conditions in that direction.

THICKNESS OF THE UPPER GREEN SHALES.

The thickness of the upper green shales on the western side of the Portsmouth syncline is probably at least 150 feet, and this is certainly the smallest possible estimate for the thickness of the green shale series exposed

at Slate Hill and southwestward. The exposed portion of the shales beneath the conglomerates at Eastons Point adds up, according to Prof. T. Nelson Dale, to at least 600 feet, with an unknown thickness of shales beneath, but even the shales exposed can not all be called green. The thickness of the upper green shales must occasionally equal 200 to 250 feet.

THICKNESS OF THE SAKONNET SANDSTONES.

The upper sandstones and shales beneath the conglomerates at Black Point have a thickness of at least 110 feet, while their total thickness at this point is evidently greater. The corresponding series at Taggarts Ferry can, however, hardly exceed that amount. Their thickness east of the river is discussed later.

The thickness of the more typical dark-blue Aquidneck shales probably exceeds 3,000 feet. The upper green shales and the Sakonnet sandstones do not add considerably to this thickness, so that an estimate of 3,000 to 3,500 feet for the Aquidneck shale series seems reasonable. Desirable as it would be to secure a better idea of the total thickness of the Aquidneck shales, this is at present impossible. The accessible data do not furnish the means for such an estimate.

NORTHERN EXTENSION OF THE AQUIDNECK SHALES.

North of Bristol Neck the Aquidneck shale series seems to lose its identity. Greenish-blue shales continue to be exposed at several points a mile north of the Warren and Fall River Railroad, but on continuing northward are soon intercalated with sandstones and conglomerates to such an extent that they can no longer be recognized as a distinct series, but evidently merge northward into the upper part of Mr. Woodworth's lower Coal Measures series.

EQUIVALENTS OF THE KINGSTOWN SANDSTONE AND AQUIDNECK SHALE SERIES NORTHEAST OF WARREN NECK.

East of Aquidneck Island and Bristol and Warren necks it appears impossible to distinguish between a lower Kingstown sandstone and an upper Aquidneck shale series. Sandstones and shales are exposed below the coarse conglomerates southwest of Swansea village. Coaly shales are

found five-eighths of a mile north of South Swansea Station. Shaly sandstones occur west of Lees River north of the railroad. At Braytons Point very coaly shales and some sandstones are exposed. Northeastward, on Sewammock Neck, sandstone is found. The exposures east of Taunton River include the arkoses resting upon pre-Carboniferous granites, both of which will be discussed later.

The section included between the coarse conglomerate of Swansea village and the arkoses of Steep Brook or Fall River must correspond in some measure to the Aquidneck shales and possibly to more or less of the Kingstown sandstones as described from the main area of the basin toward the southwest. If the section from Swansea village to Steep Brook be considered as simple in geological structure, tolerably free from local folding or marked changes of dip, a supposition by no means certain, fair estimates might be made as to its thickness. If the strata be supposed to be inclined toward the northwest at an average angle of 45°, a thickness of 10,600 feet would have approximate value, while at an inclination of 60° the thickness of section might equal 13,800 feet. The thickness of the Kingstown sandstones was placed above at 11,500 feet, and that of the Aquidneck shales at 3,000 to 3,500 feet, making a total thickness of 14,500 to 15,000 feet for the corresponding strata farther southwest. Unfortunately all these estimates are based on data either not strictly reliable or even not fairly satisfactory, especially since in the regions where the estimates are made there are areas where exposures are few, but these estimates are at least the best at present available. While it is impossible to distinguish an upper Aquidneck shale from a lower sandstone series between Swansea village and Steep Brook, yet the existence of abundant shales in the upper part of this section should be distinctly recognized as an approach to the lithological distinctions in existence farther southwestward.

SAKONNET SANDSTONES ON THE EAST SIDE OF THE RIVER.

That the upper part of the Aquidneck shales, that portion immediately underlying the coarse conglomerate series, loses its shaly character and assumes more of a sandstone nature eastward has already been noted in speaking of the exposures north of Black Point and at Taggarts Ferry, on the southeastern shore of Aquidneck Island. On the eastern side of the Sakonnet River, east of Aquidneck Island, the rocks underlying the coarse

conglomerate series consist also chiefly of sandstone. Some of the sandstone layers contain scattered pebbles, or even thin streaks of conglomerate; conglomerates with pebbles of moderate size also occur, but do not constitute an important element of the Sakonnet sandstones. Shaly layers are more common, and occasionally attain considerable thickness—for instance, in the case of the coaly shales along the shore directly west of Windmill Hill. As a rule, however, the sandstones predominate very much at this horizon. The sandstone exposures north of High Hill, and the sandstone, shale, and fine conglomerate extending from the shore west of Windmill Hill nearly to Browns Point, are characteristic exposures of this Sakonnet sandstone on the east side of the river. The shales and sandstones south of Corys Wharf may possibly represent some lower horizon in the Aquidneck shale series.

ABSENCE OF THE SHALE SERIES BENEATH THE COARSE CONGLOMERATES EAST OF THE SAKONNET RIVER.

The upper Aquidneck shales are therefore believed to merge into sandstones on approaching the present eastern border of the Carboniferous basin. And this may be true also of the lower horizons of this series. If the coarse conglomerates on the eastern side of the Sakonnet River be, indeed, the equivalents of the coarse conglomerates on Aquidneck Island and northwest of Taunton River, and if the sandstones just mentioned belong to the Sakonnet series as interpreted west of the river, very little space intervenes in most localities on the east side of the Sakonnet River between these conglomerates and sandstones and the basal arkose layers and coaly shales. The section east of the Sakonnet River must have had a somewhat different history from that on the mainland west of the bay. An extensive system of irregular faulting would seem to offer a possible explanation for this sudden diminution of the Aquidneck shale and Kingstown sandstone section. The irregularity of the dip and strike of the coarse conglomerate exposures and their areal distribution would seem to favor the existence of marked local faulting. But it is also possible that the basal arkose east of the bay is not identical in age with that west of the bay. It may belong to a higher horizon, possibly corresponding to part of the Aquidneck shale series. In that case the failure of any equivalent of the Kingstown sandstone series to appear east of the bay is not so surprising.

WEDGE-SHAPED AREAL DISTRIBUTION OF THE AQUIDNECK SHALE SERIES.

If the Kingstown series may be compared with a wedge tapering southward, the Aquidneck shales may be said to form a wedge-shaped area tapering northward, at least as far as Bristol Neck. From the northern end of this wedge-shaped mass a narrower area extends northeastward toward Taunton River. This wedge-shaped areal distribution suggests a general inclination of the southern part of the Carboniferous formation toward the south-southeast, a feature possibly to be studied in correlation with the southward pitch of the rocks involved in the various coarse conglomerate synclines and anticlines found in the southern third of Aquidneck Island. The peculiar combination of northeast with more northerly boundary lines between the sandstone and the shale series finds expression elsewhere in the sudden changes in the direction of the shore line on the various islands, in the strikes of the chief cleavage planes, and, to a certain extent, in the trends of the hills. These facts suggest that the Carboniferous series has been subjected to two systems of folding, making moderate angles with each other, the one causing folds trending more nearly north-south and the other east of north.

EQUIVALENCE OF THE KINGSTOWN SANDSTONES AND THE AQUIDNECK SHALES.

A reference to the map will show that the identifiable Kingstown sandstones are confined to the western side of the Narragansett Basin, while the Aquidneck shales belong to the middle area, so that the Kingstown sandstones border in a general way the Western Passage of the bay, while the Aquidneck shales border the Eastern Passage and a part of the Sakonnet River. It has therefore several times been a serious question whether these two formations may not be equivalent, the western Kingstown sandstone and shale series passing toward the east into a typically more shaly Aquidneck phase. An interpretation of this kind would much simplify the conception of the geology of the southern part of the Narragansett Basin. Unfortunately there are insuperable difficulties of observation at the very point where the transition between these two formations should be traced. The exposures along the Bonnet, those on Dutch Island, which do not lie far above the same, and the rocks along the western shore of northern Conanicut, along Slocums and Great ledges, all evidently belong to the Kingstown series, while the shales on southern Conanicut, from Beaver

Tail to Mackerel Cove and Dutch Island Harbor, probably even as far as Potters Cove, north of Freebody Hill, belong to the Aquidneck shales. At the former localities, sandstones and even small-pebbled conglomerates are fairly common, while at the latter conglomerates and coarse-grained sandstones are altogether unknown, and sandstones of any description are exceedingly rare. Nothing could be in greater contrast than the exposures on Fox Hill and those on the main body of Conanicut from Freebody Hill to Beaver Tail. There is no transition between the Kingstown series and the Conanicut shales in this region. The dissimilarity here is indeed far greater than farther northeast, where the Aquidneck shales contain more or less sandstone. Sandstones and even a little conglomerate occur, for instance, in the Aquidneck shales of Prudence Island, and in the shales on Aquidneck itself, especially near the base of the formation. Sandstones form a few widely distant beds also at higher altitudes in the shale series on Aquidneck Island, but sandstones are not common in the upper beds until the Sakonnet sandstones are reached. However, neither on Prudence Island nor on Aquidneck Island is it possible to recognize a transition, either lateral or vertical, from the Kingstown into the Aquidneck series.

The Aquidneck shale series is therefore most distinct from the Kingstown sandstone in the areas where the two series are most typically developed—at the nearest point of approach of these areas, at Fox Hill on Conanicut Island; and on the western side of Prudence Island the dips indicate that the Aquidneck shales overlie the Kingstown sandstones, and for the present the conclusion must be that the shales overlie the sandstone-shale series, and this has been the interpretation in this monograph.

This does not, however, overlook the facts that the shale series on Prudence Island may contain rather frequent sandstone and some conglomerate beds, that on Aquidneck Island they may contain many sandstone beds near the base and a few higher, and that in Cranston, East Providence, Swansea, and northward they contain so much sandstone, and even conglomerate, that the two formations can no longer be distinguished, but are merged into a general Carboniferous series of shales, sandstones, and to some extent conglomerates.

The distinction between Kingstown sandstones and Aquidneck shales therefore disappears in the northern part of the area comprised in the bay region of the Narragansett Basin, but the difference between these

FRETWORK WEATHERING OF AQUIDNECK SHALES, WESTERN SHORE OF PRUDENCE ISLAND.

Below high-tide mark. Notebook near center of plate is 6¼ inches long

formations farther south is sufficiently marked to warrant their separation in this part of the report.

It is not impossible that the Kingstown series is not at all exposed east of the Eastern Passage. The section between the coarse conglomerates and the basal arkoses is evidently much smaller there than on the western side of the bay, and no exposures assignable to the Kingstown series are in direct evidence.

The Aquidneck shales on the southwestern margin of Prudence Island have weathered in an irregular manner, producing many small cavities upon the surface of the shales, giving the appearance of irregular fretwork (Pl. XXIV).

FOSSILS OF THE AQUIDNECK SHALE SERIES.

Fossils are found in the Aquidneck shales at various horizons. The fossiliferous horizon at their very base has already been mentioned—for instance, in the case of the coaly shale on the western shore of southern Prudence Island. The western Portsmouth mine exposures of northern Aquidneck possibly represent a somewhat higher horizon, fern impressions, calamites, and Sigillaria occurring there. Next comes the fern locality near the termination of Corys Lane, on the western shore of the island; then the locality just east of the railroad in the gully half a mile north of Lawtons Valley, where a few ferns were found; next, a mile southeast of Carrs Point, on the western Newport-Bristol Ferry road. The fern impressions found half a mile south of the wharf on the eastern Portsmouth shore, and those found a short distance north of the Glen, may belong to about the same horizon. The fern impressions found along the roadside three-fourths of a mile northeast of Butts Hill probably represent a higher horizon. Those at the northern side of the Old Fort, on the side north of Butts Hill, are still higher in the series. If the conglomerates at Coddington Point belong to the group of coarse conglomerates overlying the Aquidneck shales, the fern impressions near the northern end of the point represent a horizon above their base. The fern locality along the coast a mile and a half north of Coddington Point at present can not be well located stratigraphically. The same statement applies with greater force to the fern locality on the western side of Braytons Point, which consists of coaly shales, such as exist near the top of the sandstone series in the more western parts of the bay region, but the precise stratigraphic position of the deposit is unknown.

CHAPTER IX.

THE PURGATORY CONGLOMERATE.

Coarse conglomerate overlying the Aquidneck shale series.—The Kingstown series is overlain by a considerable thickness of shales, here termed the Aquidneck series. These shales retain their shaly characteristics and bluish-black color to within a very short distance of the base of the overlying coarse conglomerate at Coasters Harbor Island, Coddington Point, and Miantonomy Hill.

Farther eastward, near the top of the Portsmouth syncline, at Slate Hill and southwestward, and to a less degree on both sides of the Eastons Point anticline, the upper portion of the shale series has a more greenish color, and at the first and last mentioned localities this upper greenish shale evidently lies immediately under the coarse conglomerate of these regions.

At Taggarts Ferry the bluish Aquidneck shales are exposed in the stream bed entering the bay from the west, within a very short distance from the shore. Overlying these shales is a variable series composed of bluish shales, carbonaceous shales, black fine-grained sandstones, less carbonaceous and coarser-grained sandstones, and conglomerates with the pebbles usually small. These occur in alternating beds, and have already been described under the name of Sakonnet sandstones. Immediately overlying them is coarse conglomerate.

The dark-blue Aquidneck shales are well exposed at the Glen. Southward along the shore the shales are usually more black and carbonaceous. Just before reaching Black Point an overlying series of dark shales, dark carbonaceous fine-grained sandstones, and very small-pebbled conglomerate comes in, representing a more northern variety of the Sakonnet sandstones. Overlying these sandstones is the same coarse conglomerate which was mentioned in describing the exposures at Taggarts Ferry.

East of the Sakonnet River there are no exposures of the typical Aquidneck shale variety, but the coarse conglomerates occur, and immediately beneath the latter, according to this interpretation of the geological

structure of this region, occur the shale, sandstone, and fine conglomerate beds, forming the Sakonnet sandstones east of the river, from the shore west of Windmill Hill almost as far as Browns Point. The thickness of the sandstones along this part of the shore must amount to at least 300 feet, but no accurate measurements were obtained.

Underlying the coarse conglomerate of High Hill Point is more sandstone and small-pebbled conglomerate. Immediately beneath the Fogland Point conglomerate is greenish shale. The exposures south of Corys Wharf, consisting of bluish shale with some sandstone, approach more nearly to some of the Aquidneck exposures west of the Sakonnet River than any other exposures known on the eastern side of the bay. They undoubtedly belong beneath the coarse conglomerate, and lie at about the same horizon as some of the Sakonnet sandstones farther southward.

Sakonnet sandstones within the Aquidneck shales, in transition to the coarse conglomerate.—The Sakonnet sandstones are here placed with the Aquidneck shales, owing to the frequent intercalation of shales, and because the dividing line is more readily drawn above than below the sandstones. At the same time these sandstones, with the interbedded small-pebbled conglomerate layers, are undoubtedly introductory to the coarse conglomerate series above.

Coarse conglomerate forming the latest Carboniferous rocks in the southern part of the Narragansett Basin.—The various coarse conglomerate exposures mentioned form the summit of the rocks of Carboniferous age in the localities where they are found. Under these circumstances the temptation is very great to consider them all as being of the same general horizon.

Purgatory conglomerate as a typical exposure.—The position of the coarse conglomerate at Eastons Point is perhaps the best defined. It occurs on both sides of the anticline forming the point, and the exposures on the eastern side of the anticline containing the famous Purgatory chasm can be readily traced northward to the high conglomerate ridges forming the western side of the Paradise region northwest of the reservoir. The southward pitch of this anticline is the best assurance that this coarse conglomerate occupies a higher position than shales of the Aquidneck series.

The upper green shales occur on Slate Hill at an elevation of 260 feet About a mile southward they occur at a level of 180 feet. At Eastons Point a restoration of the syncline would probably give a somewhat lower elevation to that part of the section which most nearly corresponds to the

greenish shales northward. This apparently corroborates the evidence in favor of a general southward pitch of the rocks in southern Aquidneck.

Owing to the typical development of the coarse conglomerate series at Purgatory, and its already well-known occurrence as shown by frequent references in geological literature, the name *Purgatory conglomerate* is chosen to designate those coarse conglomerates which are supposed to belong to the same horizon.

Identity of the Purgatory and the Sakonnet River western shore coarse conglomerate.—There could be no closer lithological resemblance than that between the conglomerates exposed between Black Point and Smiths Beach along the Sakonnet River or East Passage and the similar beds in the Purgatory and western Paradise regions. The lithological character of the slaty and quartzose pebbles, the inclosed oboli,[1] the great size of the pebbles, the alternation of the coarse conglomerates with sandstones, the same varieties of medium-grained granite pebbles and the same infrequency of granite as compared with quartzitic pebbles, and many other points easily recognized in the field, all suggest the identity of the two series. The presence of Aquidneck shales in the region northwest of Black Point and the eastward dip of the coarse conglomerate suggest superposition of the coarse conglomerate upon the Aquidneck shales.

Possible syncline between the two western Paradise ridges of conglomerate.—The Purgatory and western Paradise exposures and the Sakonnet River western shore exposures just mentioned dip eastward. In order to place them at the same horizon, it seems necessary to imagine at least one syncline somewhere between the two lines of exposure. The main ridge of the Paradise region, forming its western boundary, evidently dips eastward, most of the dips being between 40° and 60°. East of the same, separated by a grassy valley, is another lower conglomerate ridge, with a few very steep eastward dips, and a greater number of very steep westward dips, which can be best summarized as steep, nearly vertical, dips. This variation of dips between the two ridges admits of the suggestion that there is a syncline between them. Following the strike of the nearly vertically dipping ridge northward, exposures with almost vertical dips soon cease. Eastward-dipping exposures, however, continue to occur northward, suggesting that if there is

[1] Charles D. Walcott, Brachiopod fauna of the quartzitic pebbles of the Carboniferous conglomerates of the Narragansett Basin, R. I.: Am. Jour. Sci., October, 1898, 3d series, Vol. VI, p. 327.

a closely folded synclinal structure with its axis so far westward, it must be of limited longitudinal extent.

Hanging Rock ridge possibly the eastern side of an anticlinal fold.—The Hanging Rock coarse conglomerate ridge also agrees, lithologically, to a remarkable degree with the Purgatory-Paradise and the Sakonnet River western shore conglomerate. Its dips are very steep to the westward. If the two western Paradise ridges were considered as forming a close syncline, the Hanging Rock ridge could be regarded as the eastern side of an anticline lying east of that syncline. The various exposures of conglomerate east of the Hanging Rock ridge, in the woods and in the fields immediately east of the stream, would then necessarily require interpretation as the eastern side of a second syncline, while the Sakonnet River western shore exposures would in their turn form the eastern side of the next anticline. In the absence of clear evidence on this point, the steep, nearly vertical, western dip of the Hanging Rock ridge is almost as favorable to this interpretation as to any other, although requiring an anticlinal fold slightly overturned toward the east in order to make the steeply westward-dipping Hanging Rock ridge the eastern side of an anticlinal fold.

Dips immediately east of Hanging Rock ridge.—Opposite the middle length of the Hanging Rock ridge a small conglomerate ridge forms a promontory projecting southward into Gardners Pond. Its dip is from 80° W. to vertical. On the southeastern side of this promontory a more eastern exposure dips 60° E. Northward along the strike from this promontory the dip is 40° E., and remains east to a point east of the northern end of the Hanging Rock ridge. An exposure east of that point dips 80° E. These dips are certainly very unfavorable to any view making the Hanging Rock ridge the western side of a syncline and the more eastern exposures near by, in the woods and fields, the eastern side, as suggested in the preceding paragraph. The dips at the Hanging Rock ridge and eastward, if considered apart from any question of correlation between the Hanging Rock conglomerate and that along the western shore of the Sakonnet River, are certainly more favorable to the supposition of a local anticline, and this is the view taken by Profs. T. N. Dale, Crosby, and Barton, who visited this locality to compare dissenting opinions.

Interpretation adopted.—The interpretation adopted by the writer accepts the eastward dips of the main Purgatory-western Paradise ridge as indicative

of its position on the western side of a syncline. It ignores the fact that a smaller ridge immediately toward the east shows much steeper and sometimes somewhat western dips, and suggests instead that these more vertical dips arise in consequence of the very inflexible character of this coarse conglomerate, even under conditions of strong folding, causing the tilting of large masses at unusual angles. The thickness of conglomerate forming the lower, more eastern, of these ridges is considered entirely inadequate for correlation with the much greater mass of conglomerate forming the larger, more western, ridge, which is so great as not to admit of the interpretation of the lower ridge as forming a possible repetition of the higher one, owing to the intervening synclinal structure in which both are involved.

The thickness of conglomerate forming the Hanging Rock ridge is considered entirely inadequate for correlation with the much greater conglomerate section east of the ridge as opposite sides of the same anticline, the Hanging Rock ridge forming the western side, and the field exposures the eastern side. For this reason the Hanging Rock ridge is considered the eastern side of a great syncline, with the Purgatory-Paradise ridge as the western side. The region east of the Hanging Rock ridge is considered as anticlinal in structure, with the Hanging Rock ridge as the western side of the anticline and the Sakonnet River western shore conglomerate as the eastern side. This interpretation also ignores the eastern dips of the conglomerate exposures immediately east of the northern half of the Hanging Rock ridge, considering these again as mere evidences of the results possible when unusually hard rocks are subjected to processes of folding in conjunction with great masses of much softer underlying shales. This interpretation would give approximately the same thickness to the coarse conglomerates involved in the (1) two western Paradise ridges west of the reservoir, (2) the exposures at the Hanging Rock ridge and those immediately eastward, and (3) the western shore conglomerates along the Sakonnet River.

Southward pitch of the great Paradise-Hanging Rock syncline.—Accepting this interpretation, the Paradise region between the western Paradise ridge and the Hanging Rock ridge is to be considered as a great syncline. The conglomerate exposed along the roadside about a mile southwest of Black Point is considered the most northern exposure of this syncline. Its elevation is about

75 feet. If it lies anywhere near the base of the syncline the trough dips strongly southward, since the base of the conglomerate series near the southern end of the Paradise region must lie far below sea level. The quartzitic shales forming the central parts of the Paradise-Hanging Rock area southward are considered as pre-Carboniferous, the intercalated igneous rocks having penetrated these shales, but not the rocks of Carboniferous age.

Southward pitch of the Sakonnet River syncline.—The syncline between Smiths Beach, Taggarts Ferry, and Black Point on the west, High Hill Point on the north, Windmill Hill on the northeast, and an unexposed region now occupied by the eastern part of the lower Sakonnet River has already been mentioned. The shore exposures west of Windmill Hill as far as Browns Point must once have underlain a continuation of the coarse conglomerate series still exposed at High Hill Point and on the side of Windmill Hill, if such a synclinal structure really exists. At High Hill Point the conglomerate is exposed at sea level. Southward, opposite Taggarts Ferry and Smiths Beach, the base of the syncline must lie far below sea level, indicating a southward pitch of the syncline and adding another instance of the general southward pitching of the rocks in southern Aquidneck.

From High Hill Point to the northwestern side of Nonquit Pond, and thence to the eastern side of Nannaquacket Pond, the coarse conglomerate is exposed at about sea level and rises to about 80 feet above. The Fogland Point conglomerate is also at about sea level. The syncline probably does not extend far north of High Hill Point.

WESTERN COARSE CONGLOMERATE EXPOSURES.

Lithologically the coarse conglomerates of Miantonomy Hill and Coasters Harbor Island present all the features of the Purgatory conglomerates on the east, excepting the marked elongation of the pebbles. Since the elongation of the pebbles, wherever it occurs, is a secondary feature, it need not be taken into account.

Possible syncline immediately west of Miantonomy Hill.—At Miantonomy Hill the coarse conglomerate pitches southward at an angle of perhaps 15°, conglomerate occurring again at a lower level an eighth of a mile south of the summit of that hill. On Beacon Hill, immediately northward, a conglomerate is exposed, with pebbles usually not exceeding 8 inches in length. The over-

lying sandstone indicates also a southward pitch, and a westward dip on the western side of Beacon Hill. In a field west of Miantonomy Hill, near the railroad, coarse conglomerate dips 45° E., suggesting a synclinal structure between the conglomerate exposed in the field and that on the hill. This interpretation would demand an anticlinal structure west of the first-named exposure, a synclinal structure coming in again at Coddington Point and Coasters Harbor Island, where coarse conglomerate again appears, that of Coasters Harbor Island bearing the closest resemblance to that on Miantonomy Hill.

This interpretation of the geological structure is again very free, and is based upon two assumptions: That the conglomerate exposures on Miantonomy Hill and those at Coasters Harbor Island, lithologically alike, are also stratigraphically identical, and that the field exposures of conglomerate which dip eastward possibly belong to the same horizon.

Possibility of two horizons of conglomerate at Miantonomy Hill. — Why, however, should there not be two horizons of conglomerate, the exposures west of Miantonomy Hill underlying the coarse conglomerate forming the summit of that hill? The occurrence of coarse conglomerate low down in the Aquidneck series—in fact, according to our interpretation, at its base, in the western part of Bristol Neck—shows the possibility of coarse conglomerate lower than that which forms the summit of the rock of Carboniferous age in the Narragansett Basin. Possibly this exposure west of the hill is such a lower horizon, although not near the base of the shale series.

On the western side of the stream entering Eastons Pond from the north, in the fields north of the first east-west road, is a conglomerate exposure apparently dipping very low to the westward, so that the dip would evidently carry also this conglomerate beneath the conglomerate forming the summit of Miantonomy Hill. The exposure of conglomerate north of Eastons Pond might therefore correspond to the section west of Miantonomy Hill, the two forming a lower horizon of conglomerate, while the Miantonomy Hill exposure formed the upper horizon. To which of these two horizons would the Coasters Harbor Island conglomerate belong? The writer interprets it as corresponding to the Purgatory conglomerate. Its resemblance to the conglomerate near the summit of Miantonomy Hill is so great as to be considered conclusive of identity, notwithstanding the fact that conglomerates corresponding to these expo-

sures do not occur at intermediate localities. The absence of these conglomerates at Coddington Point is also puzzling.

Interpretation adopted.—So moderate a thickness of coarse conglomerate is exposed in the fields northwest of Eastons Pond and west of Miantonomy that it is impossible confidently to identify them with the much thicker Purgatory conglomerate. The Miantonomy Hill and Coasters Harbor Island exposures, on the contrary, suggest a much thicker section than the field localities, and show pebbles of a size more nearly corresponding with that of the coarse Purgatory conglomerate. For this reason the writer considers the Miantonomy Hill exposure equivalent to the Purgatory conglomerate, the Coasters Harbor Island conglomerate being referred to the same horizon. Whether the field exposures are to be considered as belonging to the same general horizon or not is left, for the present, an open question.

Geological position of the Newport Cliff section.—The geological position of the Newport Cliff exposures presents another important question, to which an uncertain answer must be returned. The conglomerate on Miantonomy Hill pitches southward about 15°. If it has any representative southward which is actually exposed, it is almost certainly the upper part of the Newport Cliff section, toward Ochre Point. Here conglomerate occurs in layers which are interbedded with a greater percentage of sandstone and shale than is found in the Purgatory-Paradise or in the Black Point-Smiths Beach coarse conglomerate sections. The pebbles, moreover, are commonly not so large, although several layers with fairly large pebbles occur, and locally some very large pebbles are found, a few exceeding 15 inches in diameter. Some of the largest pebbles may be seen west of Ochre Point in a very thin conglomerate layer, at the top of the conglomerate series. The sandstones and shales interbedded with these coarser conglomerates are more frequently greenish and brownish than similar rocks farther down in the cliff section.

If the upper and coarser conglomerate beds of the Newport Cliff section be considered the equivalent stratigraphically of the Miantonomy Hill section, the lower part of the Newport Cliff section at once demands attention on account of its peculiar lithological characteristics. This part of the section also contains frequent conglomerate layers, although the pebbles are rather small or of only medium size. The interbedded sandstones are often darkened by the presence of carbonaceous matter, and the

shales are frequently carbonaceous or coaly. Exposures beneath the Miantonomy Hill conglomerate are few and do not resemble very closely the lower part of the Newport Cliff section. There is no probability of a considerable amount of medium-pebbled conglomerate underlying the coarser bed at Miantonomy Hill, so that the Newport Cliff section appears very much richer in conglomerate layers in that part of the section which immediately underlies the coarser conglomerates.

If the coarse conglomerates of the Newport Cliff section be compared with the Purgatory conglomerate, then the underlying medium-pebbled conglomerates toward the "Forty Steps" and the western end of Eastons Beach must correspond to the medium-pebbled conglomerate layers of much smaller thickness beneath the Purgatory conglomerate at Eastons Point. In other words, the Sakonnet sandstones of Black Point, along the Sakonnet River, would be represented at (1) Eastons Point by a few conglomerate layers with medium-sized pebbles scattered rather irregularly among the much more abundant shales and sandstones, and at (2) the Newport Cliffs by a greater quantity of conglomerate in a section of greater thickness.

The real difficulty in the way of a satisfactory interpretation of the geological position of the Newport Cliff exposures is the paucity of outcrops between these cliffs and Miantonomy Hill, or between the cliffs and Eastons Point. Too little is also known of the rocks underlying Newport. It may be that others, who resided in Newport at the time the various sewers were constructed, have the necessary information, but all that the writer could learn was insufficient to determine the correlation of the beds. The writer's experience is that isolated exposures of small area are very unsafe for the determination of horizons where the lithological character of the rocks change so often as they do, for instance, at the Newport Cliffs. Continuous sections are needed. Until further evidence is secured the writer prefers to consider the Newport Cliff section the equivalent of the Miantonomy Hill and the Eastons Point sections in the sense described above.

Prof. T. Nelson Dale mentions that coal seams were struck in digging wells under the city of Newport. Coal seams formerly outcropped near Sheep Point, on the cliffs. Coal plants have been found near the corner of Marlborough and Farewell streets.[1] In his published sections he places coaly

[1] In a sewer tunnel made nearly ten years ago, between Bellevue avenue and the first avenue parallel to it on the east, and not far north of Ochre Point, Carbonaceous shale formed the rock exposure. It was examined by Professor Dale.

shales beneath the city of Newport. The contact with the top of the coarse conglomerate is unconformable. Coaly shales of considerable extent are, however, suggestive of Aquidneck shales, since these are the only shales having any great distribution over wide areas. This would place the rocks beneath the city of Newport in the Aquidneck series and beneath the cliff exposure. Either a fault or a close overturned synclinal fold must be hypothesized to account for the present position of these rocks.[1] Professor Dale notes the presence of slates and conglomerates at Emmanuel Chapel, at the corner of Spring and Perry streets. Conglomerates occur in Morton Park.

Portsmouth synclinal conglomerate.—Near the summit of the Portsmouth syncline the upper green shales begin to contain sandstone and some small-pebbled conglomerate layers, overlain at various localities, it seems, by sandstone and coarse conglomerate. Coarse conglomerate occurs, for instance a third of a mile south of Butts Hill, in the Portsmouth camp-meeting grounds north of Quaker Hill, and on the east side of the Newport-Bristol Ferry road, half a mile west of Quaker Hill. This conglomerate, associated with much sandstone, is believed to have been introductory to the coarse conglomerate series, which once must have lain above it.

East of the Portsmouth syncline there must have been an anticline (merging southward perhaps into a monocline), in order to enable the coarse conglomerate to appear at sea level on the eastern side of the Sakonnet River from Fogland Point to the eastern side of Nannaquacket Pond.

Conglomerates of Warren Neck and Swansea.—The coarse conglomerate exposures from the western side of Warren Neck to Coles Station, along both banks of Lees River north of the southern road to Fall River, and thence northward to Swansea village, as well as the exposures found north of the western Warren Neck exposures, at Luthers Corner and in western Swansea, are all considered as corresponding to the coarse conglomerate series lying to the southward.

Thickness of the coarse conglomerate.—The thickness of the coarse conglomerate in the Black Point-Taggarts Ferry section was estimated to be at least 380 feet. This may not include the entire section, a part of the conglomerate

[1] Prof. T. Nelson Dale, in his paper on the Geology of the Mouth of Narragansett Bay (Proc. Newport Nat. Hist. Soc., Document 3, pp. 6-14, Newport, R. I., 1885), gives a somewhat different interpretation of the general section of this part of the basin from that presented by Dr. Foerste. The most notable difference concerns the position of the quartzite conglomerate, which Dale places below the coal-bearing portion of the section.—N. S. S.

being possibly not exposed. The Purgatory-Paradise section of coarse conglomerate may range between 600 and 450 feet in thickness, according as the lower and eastern one of the two ridges is or is not included in the section.

Fossil localities.—Ferns are found in Woods Castle, in a coaly shale which belongs stratigraphically within the coarse conglomerate series. They occur also in the Newport Cliffs a short distance south of Marys Seat, in a coaly black shale about 14 feet thick, overlying a conglomerate bed about 11 feet thick, with pebbles often 4 inches thick. Fossil ferns are still more common in the coaly shales southwest of Ochre Point, near the top of the sea wall. The position of these coaly shales is not accurately known. They lie west of the Newport Cliff section with its conglomerates, but may belong to the shale series exposed beneath Newport. This, according to the writer's interpretation, would place them below the coarse conglomerate.

CHAPTER X.

THE ARKOSES AND BASAL CONGLOMERATES.

NATICK ARKOSE.

From Natick to Cranston.—Along the steep hill face from Natick, Rhode Island, for $2\frac{1}{2}$ miles northward into Cranston, extend the arkoses and quartzite conglomerates that form the lowest rocks of Carboniferous age on the western side of Narragansett Basin. The eastward dip of these rocks shows their position beneath the Kingstown series, which lie farther eastward. Near the fork of the road, half a mile northwest of Natick, a coaly black shale overlies the arkose and is itself overlain by a quartzitic sandstone containing large quartzite pebbles. The arkose consists largely of detrital quartz derived from decayed granite, and is usually found near those localities where the immediately underlying pre-Carboniferous rocks consist chiefly of granite. The quartzite conglomerate is usually found near pre-Carboniferous quartzite beds, and near contact with the latter the round pebbles give way in places to those of such angular contours as to warrant giving the name of breccias to the lowest layers. This is especially true of the exposures at Alexander McTeer's house, north of Natick. Granite pebbles are rare, owing to lack of firmness on the part of the granite in the original ledges at the time the arkose was formed. Of course the arkose forms a part of the detrital material between the pebbles of the coarse conglomerates, and quartzite pebbles are not rare in some of the beds of arkose. In some cases the basal arkoses and quartzitic conglomerates do not exceed 100 feet in thickness, and a thickness of 200 feet seems not to be attained in any single set of exposures. Some of the pebbles in these basal conglomerates are 15 inches in length.

Northward, in the southern part of the field studied by Mr. Woodworth, the basal arkoses and conglomerates do not long continue to be exposed, although the steep escarpment still outlines approximately the position of these basal deposits.

The basal arkose and conglomerate beds along the western border of the Carboniferous basin are believed to represent the oldest Carboniferous rocks in the areas bordering Narragansett Bay. They are not a formation

distinct from the Kingstown series, but represent the lowest beds of the Kingstown sandstones and shales. The detrital material of which they are composed is evidence of the fact that areas of granite lay sufficiently near to provide the quartz and cementing material of the arkose. The angular breccia conglomerate at places north of Natick suggests that both granite and quartzite existed at no great distance from the present location of these beds. If this surmise be correct, we have a right to assume the existence of land areas somewhere in this region. This does not demand that the present granite and quartzite escarpment should have been a shore line at the time the Carboniferous deposits of the Narragansett Basin were formed. It is not probable that the land areas of that time were bordered by such straight and abrupt escarpments.

The present granite and quartzite escarpments had probably the following history: Before the deposition of the Carboniferous deposits a widely extended area of granite, quartzites, and pre-Carboniferous shales formed the floor of the basin. Part of this floor was above water level, and furnished materials for arkose and conglomerates. The lowering of the basin and the progressive overlapping of later deposits may have entirely covered up these land areas and carried the shore line much farther westward. The direction and location of these early shore lines are in reality not known. Subsequent to the deposition of the Carboniferous the rocks of the entire basin were subjected to strong folding, the axes of the folds running north-south. The granite and quartzite escarpment on the western side of the bay represents the bed of the Carboniferous deposits, brought up on the western side of a great synclinal fold. The escarpment is due to subsequent erosion.

Base of the Carboniferous south of Natick.—A mile south of Davisville, along the railroad, an abundant supply of conglomerate is to be referred rather to the base of the Kingstown series than to the basal beds above mentioned. From Natick to East Greenwich and Wickford Junction the steep escarpment continues to indicate approximately the horizon along which the basal deposits occur, but no exposures are found.

South of Wickford Junction it is impossible to identify the basal deposits of the Carboniferous series. It is possible that they are not exposed.

Probable relations between the various granites and pegmatites and the Carboniferous beds.—The writer is inclined to favor the view that the Carboniferous series once

PEGMATITE DIKES CUTTING KINGSTOWN SHALES SOUTH OF WATSONS PIER, RHODE ISLAND.

extended from the shore exposures near Saunderstown and the Bonnet over unbroken areas as far west at least as McSparran and Tower hills, and covered even Boston and Little necks as far south as Narragansett Pier. The basal Carboniferous of these regions probably rested upon an extensive pre-Carboniferous granite area. In consequence of folding, the pre-Carboniferous granite was raised toward the west of the Tower and McSparran escarpments and along the area now occupied by Little and Boston necks, while the Carboniferous was lowered into a synclinal tract lying between these two regions along the Cove and the Pattaquamscott, and was by later denudation severed from the Carboniferous east of Boston Neck.

There is undoubted evidence of faulting in the Carboniferous area east of Boston Neck. The temptation is very great to account for the alternation of granite and Carboniferous rock, in part at least, by faulting. Some of the occurrences of detrital, presumably Carboniferous, masses in the granite areas, however—for instance, those at Narragansett Pier and at Clump Rocks light-house—could be explained as cases of Carboniferous rocks once overlying the granites, but subsequently broken up and folded in with the granites, or faulted down into them by later disturbances, only remnants of the Carboniferous rocks remaining, owing to denudation. Or else they must be considered as fragments of Carboniferous rocks caught up by post-Carboniferous granites. Unfortunately, post-Carboniferous granites are not known anywhere in the field here investigated.

Where the Carboniferous rocks are traversed by dike-like rocks, the latter on closer examination almost invariably turn out to be pegmatitic in structure, so that the pegmatites are, as a rule, readily identified as post-Carboniferous. These coarse pegmatites traverse the Carboniferous rocks rather frequently south of Hazzard's quarry and Saunderstown as far as the region northwest of the cove, and are especially well exposed at Watsons Pier (Pl. XXV; see also Pls. XVIII and XIX, pp. 242, 244). But the mass of pegmatite southwest of Wesquage Pond, on the hill, seems to belong to the Boston Neck series of exposures, and appears to connect with pre-Carboniferous granites as though the latter were in reality post-Carboniferous. The conditions are perplexing and require more study. It may be that careful observations might lead to more definite results, but to the writer conclusive data seem to be lacking, although he considers the general mass of granites as pre-Carboniferous.

The question suggests itself whether Indian Run represents another syncline within the granite area which contains Carboniferous rocks. This area has not been carefully investigated. The writer is inclined to consider McSparran and Tower hills as marking the most western exposures of Carboniferous rocks in the basin, without any attempt to assert, however, that in times preceding the folding and subsequent denudation the Carboniferous rocks could not have extended farther westward. If it be remembered that the Carboniferous deposits half a mile south of Bridgetown and along southern Tower Hill owe their high inclination to folding, it will be seen from a restoration of these beds to their original horizontal attitudes that Carboniferous beds must have once extended farther westward, making the western shore line pass west of Tower Hill; how much farther west is not known.

TIVERTON ARKOSE.

From Steep Brook to Nannaquacket Pond.—Along the pre-Carboniferous escarpment extending from Steep Brook to Tiverton Four Corners a number of exposures of arkose occur. Since this escarpment consists almost entirely of granite, any overlying basal Carboniferous rocks are apt to include arkose beds. The latter were formerly well exposed at Steep Brook, but this is no longer the case. A fine exposure occurs in Fall River, another at Townsend Hill in the northwestern end of the town of Tiverton, one at the quarry northeast of Tiverton railroad bridge, and there are several exposures along the escarpment east of Nannaquacket Pond in Tiverton. In all of these localities carbonaceous shales are more or less intimately associated with the arkoses. At Steep Brook and Fall River these were fern bearing. East of Nannaquacket Pond and at Fall River the arkoses and coaly shales alternate repeatedly. At Steep Brook and the quarry northeast of the Tiverton railroad bridge conglomerate beds occur in close connection with the arkose series. The fact that these conglomerates contain quartzite pebbles similar to those in the Natick conglomerates and that the pebbles in places attain a length of 6 inches does not simplify the problem, since pre-Carboniferous quartzites are practically unknown on the eastern side of the basin. The pre-Carboniferous quartzites on the eastern side of the basin may have been removed by subsequent erosion, but there is no good reason for assuming their former existence here. The thickness of the Tiverton arkose series is usually less than 100 feet and is nowhere known to exceed 200 feet.

South of Nannaquacket Pond.—The steep escarpment southeast of Nannaquacket Pond locates approximately the line along which the arkose beds may occur farther southward.

Equivalence of the Tiverton arkoses to those near Natick.—The coarse conglomerates assigned to the top of the Carboniferous series on the eastern side of the basin overlie these arkoses within such a limited distance that it seems hardly credible to suppose that if the coarse conglomerates along the Sakonnet River correspond to the Purgatory conglomerates the arkoses on the eastern side of the basin may correspond to the Natick arkoses and conglomerates. Yet something of this relationship must be assumed, with the possibility, however, of considering the Tiverton arkoses perhaps not so old as those occurring on the western side of the bay, their basal position not certifying to absolute equality of age with the Natick exposures, but only to their early deposition as compared with other deposits on the eastern side of the Carboniferous field. For the present, faulting is assumed to account, in part, for the remarkably short distance intervening between the coarse so-called Purgatory conglomerate in these regions and the basal Tiverton arkoses, but the absence of the Kingstown series would also partly explain the facts. The escarpment from Steep Brook to Tiverton and thence east of Nannaquacket Pond indicates that the eastern floor of the basin, upon which the Carboniferous rocks were deposited, consisted largely of granitic rocks. Subsequent folding has placed them upon the eastern side of a great synclinal fold, and subsequent denudation has left behind the present escarpment. The original contours of the Carboniferous basin are unknown.

SACHUEST ARKOSE.

The western and southern shores of Sachuest Neck, the northern shore at Flint Point, and a small exposure offshore at a headland a quarter of a mile south of Flint Point consist of arkose with which more or less coaly shale is interbedded. Lithologically it strongly resembles the exposures east of Nannaquacket Pond, and it contains ferns in the shale beds, as was also the case at Fall River and Steep Brook. If the writer's view as to the geology of this region is correct, the arkose of Sachuest Neck rests upon Cambrian conglomerate and shale, and derived its materials from pre-Carboniferous granite. The total thickness of these arkose beds may amount to 200 feet.

CONANICUT ARKOSE.

On the eastern side of Mackerel Cove arkose is found exposed north of the granite area. It is evidently composed of the detrital material derived from the granite, and the latter is considered pre-Carboniferous.

The statement that the arkose underlies the green shale is an assumption. The thin arkose layers in the black shale at Beaver Head should be noted in this connection, since they evidently occur at the base of the Aquidneck shale series. Possibly the Mackerel Cove arkose is also contemporaneous with part of the Aquidneck shales.

ROSE ISLAND AND COASTERS HARBOR ISLAND ARKOSE.

Arkose and black shale occur on Rose Island and at the southern end of Coasters Harbor Island. The writer has felt strongly inclined to consider the arkose exposed on Conanicut and on the islands last mentioned as deposits formed in the proximity of a great pre-Carboniferous granite area, without any attempt to closely synchronize the various exposures. Thus, the arkose at the southern end of Coasters Harbor Island may belong, as far as relative age is concerned, higher in the Carboniferous series than the arkose on Conanicut Island. The fact that it appears so close to the coarse conglomerate on Coasters Harbor Island suggests this. But this is another point which must be left doubtful.

If the green and purple shales of the Newport Harbor Islands, of Newport Neck, and of Sachuest Neck are of Cambrian age, as suggested, these shales, together with the granite, probably formed exposed land areas in the near vicinity in early Carboniferous times. The progressive overlapping of Carboniferous deposits caused arkose beds to be formed, resting upon the lowered Cambrian formations. This would account for the close geographical association between arkose and green shale or other pre-Carboniferous rocks in these areas. Faulting has obscured this relation.[1]

Arkose is also found west of Ochre Point, east of Newport. Perhaps in all of the cases here cited, from Conanicut, Rose Island, Coasters Harbor Island, and west of Ochre Point, the arkose is to be considered as contemporaneous with some part of the Aquidneck shale series.

The arkose on Conanicut may reach a thickness of 100 feet. The deposits on Rose Island and Coasters Harbor Island are much less thick.

[1] T N. Dale, Am. Jour. Sci., 3d series, Vol. XXVII, pp. 217–228, 282–289, map, 1884.

CHAPTER XI.

THE PRE-CARBONIFEROUS ROCKS.

The pre-Carboniferous rocks of the basin usually consist of granite, often rendered gneissoid by shearing. In a number of localities undoubted clastic rocks appear. This is true, for instance, of the western third of Newport Neck, from Brentons Point to Brentons Cove, of all of the Newport Harbor Islands, and of some of the shore exposures along the southern margin of the harbor. The shales here are often purplish and sometimes contain thin layers of limestone. At various points along the southern Newport Harbor region rather thick layers of limestone occur, in striking contrast to the absence of limestones in the Carboniferous series.[1] The purplish or greenish shales are frequently interbedded with a more quartzitic greenish or whitish rock, sometimes shaly, but usually more like argillite.

Similar rocks are found along the eastern shore of Sakonnet River from Browns Point to the granite area a mile north of Sakonnet Breakwater. The same purplish-colored shales, with occasional very thin limestone layers, and the same greenish argillitic or quartzitic rocks are seen here.

The purplish shales, with their thin interbedded limestones just mentioned, remind the observer of the Olenellus Cambrian rocks found in eastern Massachusetts. While not identifying these more southern exposures with the same precise horizon northward, the writer is of the opinion that eventually the purple shales of Newport Neck and Little Compton may prove to be Cambrian rocks.

Farther inland, eastward, the exposures consist of rock varying between quartzite and argillite, with abundant parallel shearing planes, often showing the effects of subsequent folding. The Cambrian beds in Little Compton, east of the shore exposures, are often decidedly quartzitic. So are also some of the shore exposures. It is not unlikely that these exposures include more than one horizon, paleontologically considered.

[1] Prof. T. N. Dale saw, April 25, 1883, in the possession of Mr. Coggeshall, a blacksmith at Newport, carbonaceous shales with fragments of 10 specimens of Aviculopecten, said to have come from Portsmouth mine. Sketches of these fossils were submitted to Professor Von Zittel. Their importance lies in the fact that, if authentic, they are the first known evidence favoring the presence of salt water during Carboniferous times in New England.

The whitish rocks between the conglomerate ranges in the great Paradise-Hanging Rock syncline resemble strongly the more quartzitic exposures away from the shore, east of the Sakonnet River.

Quartzites occur well exposed (1) west of Natick, (2) along a road a short distance east of Natick, (3) southwest of the town, (4) along the northern side of Bald Hill, (5) on a knoll directly east of that hill, and elsewhere. Possibly various exposures west of East Greenwich, east of Nonquit Pond, and in the neighborhood of Tiverton belong here. The quartzites west of Natick have furnished the pebbles in the basal conglomerate of the Carboniferous. Pebbles of similar character occur also in all the overlying conglomerates as far up as the Dighton conglomerate.

In the quartzite pebbles of (1) the conglomerate between the Saunderstown sandstone series and (2) of the Aquidneck shale series on the western side of Prudence Island fossil oboli occur.[1] They are found also (3) in the conglomerates along Newport Cliffs, and (4) in the coarse conglomerates at Eastons Point, (5) in the Paradise ridges, (6) along the western shore exposures of the Sakonnet River, and also (7) east of that river north of Tiverton Four Corners. These oboli appear identical with fossils from the passage beds between the Cambrian and Lower Ordovician of Great Belle Island of Newfoundland. Hence they are either of late Cambrian or early Lower Ordovician age. Notwithstanding the great abundance of quartz pebbles with oboli, however, the quartzite containing oboli has never been found in situ. It may be that the Natick quartzite is a remnant of the old Cambrian quartzite, but since it contains no oboli this can not be determined.[2]

Considering the great abundance of quartzite material in the coarse Purgatory conglomerates, the quartzite must have once occurred in considerable thickness over wide areas. It is not improbable that the quartzite once occupied a considerable part of the area now occupied by pre-Carboniferous granite. Subsequent erosion appears, however, to have effectually denuded these areas of the quartzite beds, excepting in isolated localities, as at Natick. If the pebbles were derived from large exposures

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[1] The following species have so far been discovered in the quartzite pebbles derived from southeastern Rhode Island and Massachusetts: *Obolus* (*Lingulobolus*) *affinis*, *O.* (*L.*) *spissus*, and *Obolus* (*Lingulella*) *rogersi*.

[2] Charles D. Walcott, Brachiopod fauna of the quartzitic pebbles of the Carboniferous conglomerate of the Narragansett Basin, R. I.: Am. Jour. Sci., October, 1898, 3d series, Vol. VI, p. 327.

of quartzite lying as far north as Newfoundland and carried southward by glaciers, the absence of other pre-Carboniferous rocks among the pebbles is striking.

LITTLE COMPTON AND NEWPORT NECK SHALES.

The distribution and general characteristics of the shales in western Little Compton and along the western shore of Newport Neck have already been sufficiently described in Chapters V and VI, pages 281 and 316. The shales in question are closely related lithologically, and are evidently not similar to any known Carboniferous deposits of the basin. The characteristic feature is evidently the presence of thin layers of dolomitic limestone in both areas, and the presence at various points along southern Newport Harbor of quite thick beds of a white limestone, weathering to brown. The limestone suggests a marine origin for these shales, while the Carboniferous of the basin is evidently a fresh-water deposit. Not a single marine fossil has so far been found in the Carboniferous rocks, and no trace of limestone beds has been discovered in them. (See footnote on page 381.) Under these circumstances the Little Compton shales and the Newport Neck shales must evidently be consigned to some other geological horizon. The only other horizons so far determined by fossils in eastern Massachusetts are the Olenellus and Paradoxides Cambrian and the Carboniferous. The Paradoxides Cambrian has so far not shown the presence of limestone beds, nor are the shales ever reddish. The Olenellus Cambrian shales are, however, often reddish, often include very thin limestone beds, and at all the localities named include also limestone beds 6 to 8 inches in thickness. This suggests the possibility of the Little Compton and Newport Neck shales being of Olenellus Cambrian, or at least of Cambrian age. Of course, the finding of fossils will afford the only certain means for identifying the horizons of these beds.

QUARTZITES OF NATICK.

The quartzite on the northern side of Bald Hill, along the escarpment northwest, west, and southwest of Natick, and at various points along the road between Drum Rock Hill and Natick, has already been described in connection with the general geology of the southern part of the Carboniferous basin. These quartzites are, however, pre-Carboniferous. The same may be said also of the quartzites occurring from Natick northward

along various parts of the escarpment and thence up the Blackstone Valley as far as Ashton and Manville.

The question as to the geological position of these quartzites is very important, but at present is without a solution. On lithological grounds alone they might be considered of Cambrian age, but there is little real basis for such a determination. Perhaps the best reason so far known for considering these quartzites as of Cambrian age is the abundant occurrence of Cambrian quartzite pebbles in the Carboniferous conglomerates of the Narragansett Basin. Quartzite pebbles occur at all horizons, from the conglomerate beds just overlying the basal arkoses to the uppermost layers of the coarse Purgatory conglomerate. The lowest horizon at which these quartzite pebbles contain fossil oboli, however, seems so far to be in the conglomerate beds between the Saunderstown sandstone and Aquidneck shale series on the western side of Prudence, and with less certainty on the western side of Bristol Neck and northwest of Riverside. They occur in far greater abundance in the coarse Purgatory conglomerate, being commonly found in any considerable exposure where long-continued search has been made for the entire length of Aquidneck Island and the eastern shore of the Sakonnet River. They occur again in the corresponding coarse conglomerate at Dighton, and southwestward.

A few of the localities where quartzite pebbles with fossil oboli have been found in situ have been indicated on the accompanying geological map. These fossil oboli belong probably to some late Cambrian horizon. Hence the quartzite deposits elsewhere in the basin, especially those near Natick, in which we are most interested, may also be of late Cambrian age.

After a careful comparison of the quartzite pebbles in the quartzites at Natick and elsewhere, it must be admitted, however, that the lithological resemblance is not very close. The varied coloring shown by different fossiliferous quartzite pebbles, especially a rather common tint of faintly dark blue, altogether fails in the quartzite exposures so far examined. The whiter more vitreous quartzite localities, moreover, do not present the same cleavage as the whiter fossil-containing pebbles. Furthermore, when the considerable frequence of oboli-containing pebbles is considered, it is rather perplexing to find the quartzite localities in question apparently without fossils.

HOPPIN HILL, A GRANITE MASS SURROUNDED BY CAMBRIAN, NORTH ATTLEBORO, MASSACHUSETTS. LOOKING WEST.

While, therefore, the suggestion that the pre-Carboniferous pebbles may be of late Cambrian age seems to be the only one possible at present, the very slender basis upon which this suggestion rests should not be left out of view.[1]

[1] The origin of these fossiliferous quartzite pebbles, as well as the question of their age, has been discussed by Mr. Woodworth in his part of this monograph. It seems from Dr. Foerste's presentation of the matter that no considerable importance can be attached to the suggestion that these pebbles are derived from the Natick or other known quartzites which occur in the basin.—N. S. S.

CHAPTER XII.

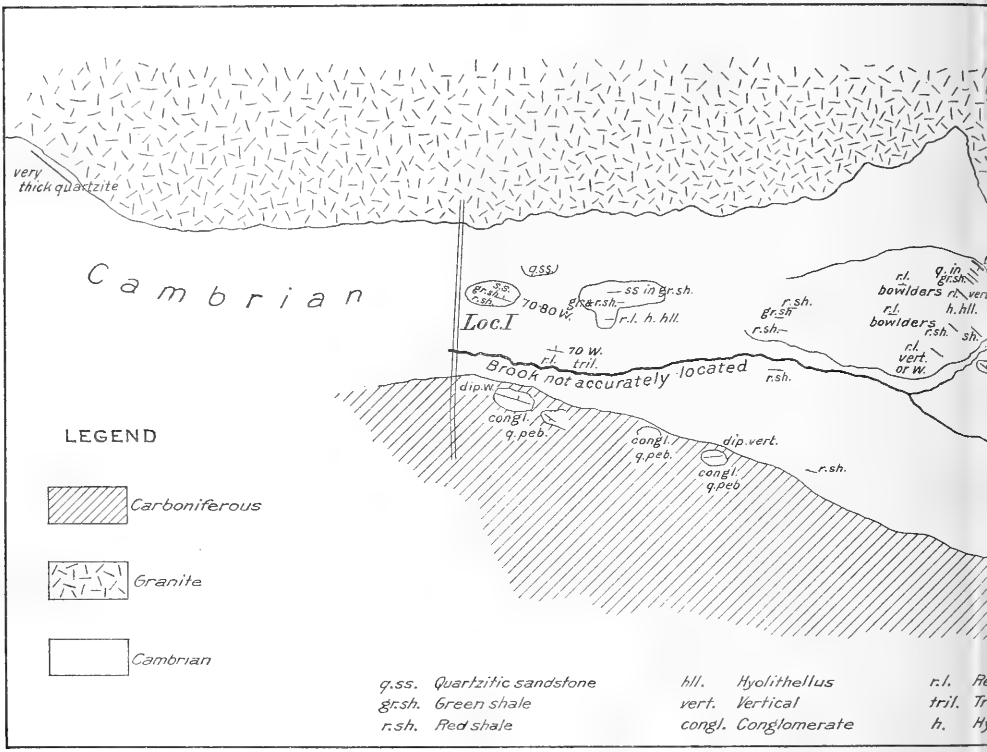
THE CAMBRIAN STRATA OF THE ATTLEBORO DISTRICT.

Among the most interesting results of the examination of the geology of the Narragansett Basin has been the discovery of a number of small Olenellus Cambrian exposures. The first of these, locality 1, directly east of Hoppin Hill (Pl. XXVI), and a mile southwest of North Attleboro, was discovered by Prof. N. S. Shaler long before the United States Geological Survey began its work here, but the horizon to which the fossils from this locality belonged was not determined until the publication of Bulletin No. 30 of the United States Geological Survey, by Mr. C. D. Walcott, in 1886, made more widely known the Olenellus Cambrian fauna of this country.

At locality 1 were found *Hyolithes princeps?* and *Hyolithellus micans?* in considerable abundance; a small form of *Stenotheca rugosa* was fairly common, and a species described later as *Salterella curvata* was also numerous. The operculum of Hyolithellus has so far not been found, but the general Cambrian facies of the fauna at locality 1 was readily recognized as early as 1887. In the fall of that year the writer was sent into the field to collect fossils, and the result was the discovery of locality 2, a third of a mile north of locality 1, which has furnished almost all of the fossils described from the Olenellus Cambrian of Massachusetts, and of locality 3, a mile directly west of locality 2, in the open fields west of a little stream, and at the northern end of a long farm lane. The number of species found at locality 3 was small, but it added to our information regarding the areal distribution of the Olenellus Cambrian in this part of the field.

The results of these investigations were published as an appendix to a preliminary report on the geology of the Cambrian in Bristol County, Massachusetts, in 1888.[1] In the determination of species, the figures of Bulletin No. 30 (United States Geological Survey) were followed very closely. When widely different forms were figured under the same species, the description was followed as well as possible. The collections the writer was able to examine at that time afforded but little assistance in

[1] Preliminary description of North Attleboro fossils, by N. S. Shaler and August F. Foerste: Bull. Mus. Comp. Zoöl. Harvard Coll., Geol. Series, Vol. II, pp. 27–41, pls. 1–2, Oct., 1888.



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CAMBRIAN FOSSI

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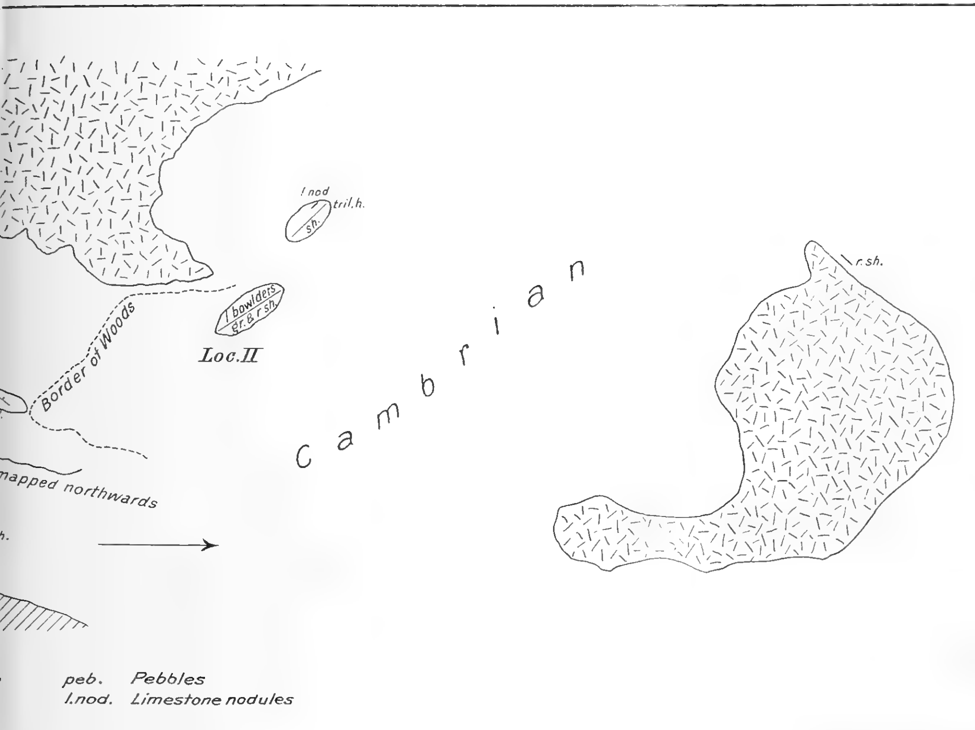

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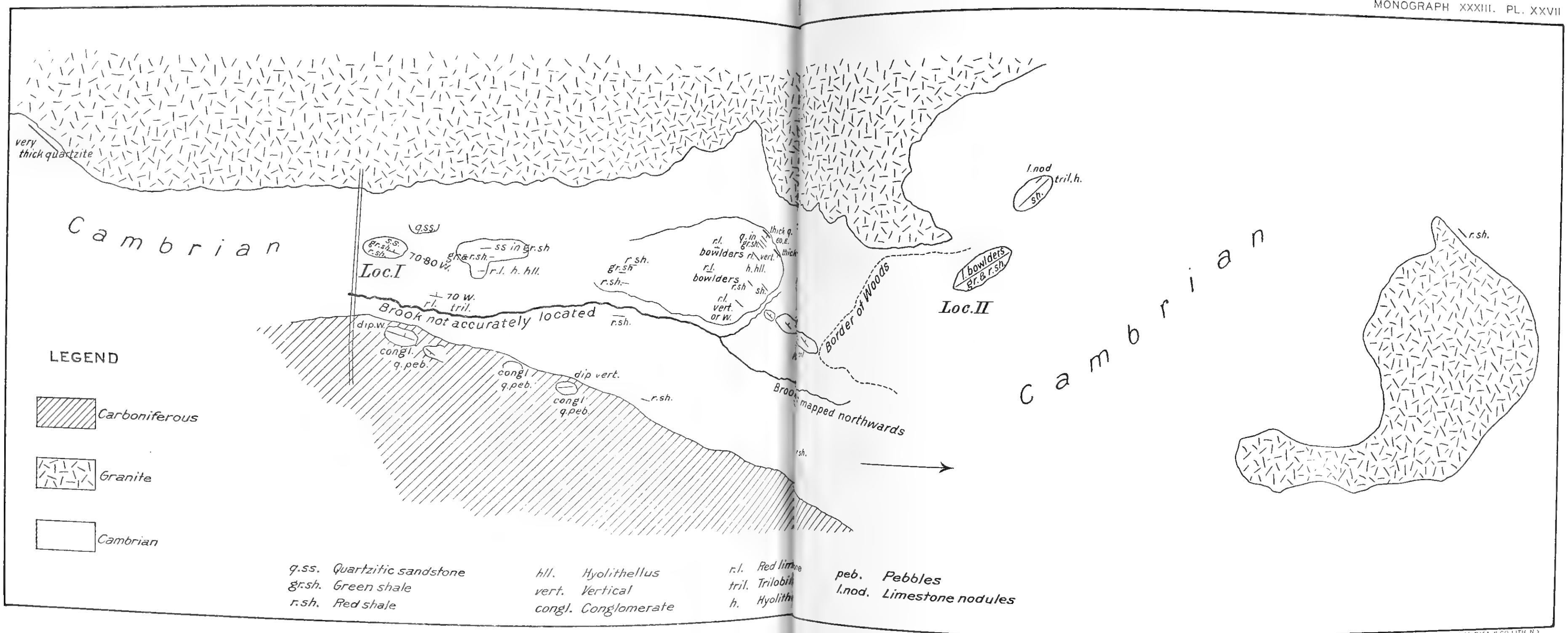
MAP

CALITIES I AND II

TH ATTLEBORO

400 600 FEET



JULIUS BIEN & CO. LITH. N.Y.

SKETC MAP
O
CAMBRIAN FOSSIL CALITIES I AND II
SOUTHWEST OF TH ATTLEBORO

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200 0 20 400 600 FEET

the determination of species. The result was naturally a number of errors. The worst of these was the reference of a small head of some species of Olenellus to the genus Paradoxides. The specimen found was a cast of the lower surface of the chitinous envelope of the head, and apparently showed facial sutures, the nonexistence of which in the genus Olenellus was already suspected at that time. It is now very well known that the position of facial sutures is indicated by grooves on the lower surface of the protecting envelope of the head (exoskeleton), a cast of which could erroneously give the idea of a partial separation of the free cheeks at the facial suture. In spite of this incorrect reference of the cast in question, the fauna was recognized as being of the Olenellus Cambrian horizon.

In consequence of the discovery of an Olenellus Cambrian fauna in the red shales and limestones southwest of North Attleboro, the red shales, sandstones, and conglomerate farther east, and, in fact, wherever found for miles around, were considered of Cambrian age. Owing to their general westward dip they were even viewed as anteceding the fossiliferous beds. The report, however, had scarcely been published when, early in 1889, the writer found loose bowlders of red sandstone with well-preserved specimens of calamites in the hills southwest of the southern end of the reservoir pond south of North Attleboro. In consequence all the red shales, sandstones, and conglomerates just described as Cambrian, excepting the shales occupying the valleys of localities 1, 2, and 3, were referred to the Carboniferous. In the writer's thesis, On the Igneous and Metamorphic Rocks of the Narragansett Basin (Harvard Univ., 1890), these red phases of the Carboniferous were described as a group of the Carboniferous, the Wamsutta. After this thesis had been presented, in the spring of 1890, Cordaites leaves were found in situ, west of the road, two-thirds of a mile southwest of the reservoir pond. At a later date Mr. J. B. Woodworth discovered abundant stems of calamites in an exposure on the north side of the road to Attleboro Falls, about two-thirds of a mile southeast of the North Attleboro post-office; and finally, in 1895, the writer found a poorly preserved specimen of calamites in the arkose beds in the northwestern part of North Attleboro, north of Division street.[1]

The result of these discoveries has been of considerable importance in

[1] It should be noted that in 1880 Crosby and Barton recognized the Carboniferous age of the red beds in the Norfolk County Basin and inferred from this a similar age for the red rocks about North Attleboro, but they did not discover the fact that a portion of these beds were of Cambrian age.—N. S. S.

arriving at a correct knowledge of the lithological characteristics of the Olenellus Cambrian in eastern Massachusetts. Instead of being a formation in which sandstones and conglomerates form a predominating element, the Olenellus Cambrian of eastern Massachusetts, as at present recognized, consists chiefly of reddish and greenish shales and slates with whitish and reddish layers and nodules of limestone. Sandstone beds are known at almost all exposures, but form only a very unimportant element of the Olenellus Cambrian, as far as this horizon has been definitely recognized.

Some sandstone is, for instance, found associated with the reddish shales and limestone beds discovered in 1889 by the writer at locality 4, just north of the State line, a short distance east of the road leading from West Wrentham to Diamond Hill.

North of Mill Cove, in the Boston Basin, the Olenellus Cambrian (fossils discovered by the writer in May, 1889) consists chiefly of reddish and cherty greenish slate, including limestone nodules, and a few limestone beds, the latter containing *Hyolithes communis* and *Hyolithellus micans.*

At the southern end of Nahant the Olenellus Cambrian (fossils first recognized by the writer[1] in April, 1889, but previously discovered and not identified by Prof. Alfred C. Lane and J. Sears) consists of cherty greenish slate, with two or three white limestone layers, the latter containing *Hyolithes communis* and a small form of *Stenotheca rugosa.* Near the southwestern angle of Topsfield similar cherty greenish slates occur, the fossiliferous limestone being, however, hard and light blue in color.

At Achelaus Hill, in West Newbury, Mr. John Sears reports another instance of cherty slates similar to those at Nahant, and containing similar fossils.

No great masses of sandstone and conglomerate have so far been recognized as belonging to the Olenellus Cambrian horizon, or as being closely associated with the same.

CAMBRIAN BROOK LOCALITIES.

LOCALITIES 1 AND 2, SOUTHWEST OF NORTH ATTLEBORO.

A great mass of quartzite on the southeastern side of Hoppin Hill may belong to the Olenellus Cambrian. Fragments of reddish shale occur in the soil farther eastward.

[1] See The paleontological horizon of the limestone at Nahant, Massachusetts: Proc. Boston Soc. Nat. Hist., Vol. XXIV, 1889.

At locality 1, just north of the road leading eastward down from Hoppin Hill, there is a small knoll, composed chiefly of shale, more greenish westward, where it includes a few thin white quartzite layers, strike N. 10° E., dip 80° W.; reddish eastward, where the shale includes limestone layers, pinkish where fresh, red where strongly weathered. (Map, Pl. XXVII.)

In the limestones were found the following fossils: *Stenotheca rugosa* var. *pauper*, *Pleurotomaria* (*Raphistoma*) *attleboroensis*, *Fordilla troyensis?* left valve, *Hyolithes princeps?* *H. billingsi*, *Hyolithellus micans?*, *Salterella curvata.* Northeast of locality 1, 50 feet, are found some very small exposures of red shale with limestone layers, including *Agraulus strenuus*, strike N. 10° E., dip 70° W. Farther northward 100 feet, a little east of north from locality 1, is another knoll with red shale on the eastern side, containing red limestone with Hyolithes and Hyolithellus. The ridge itself is composed of greenish and reddish shales on the eastern face, and greenish shale including thin sandstone and quartzite beds along the middle and western sides.

About 150 feet north of the last-mentioned knoll, or 340 feet north of locality 1, reddish shale, abundantly cleaved in various directions, occurs just west of the stream, and another exposure occurs near by on the eastern side of the stream. West of these localities green and red shales occur, also much cracked; 50 feet farther north, and again 110 feet farther north, limestone bowlders occur. Another limestone bowlder is found about 50 feet west of the last-mentioned bowlder and about 525 feet a little west of north of locality 1.

About 560 feet almost directly north of locality 1 and just south of a small stream red shale is found including thick red limestone beds in almost vertical position. Thirty-five feet northwest of the same red shale occurs; 50 feet directly westward occurs limestone containing Hyolithes and Hyolithellus, strike N. 50° E., dip vertical.

Thirty feet northwestward is the beginning of a set of greenish shales including numerous quartzite layers, the most eastern one 12 inches thick, the intermediate ones a few inches in thickness, the most western layer nearly 2 feet thick and white in color, strike N. 21° E., dip 60° E. About 25 feet northeast of this most western exposure a similar thick quartzite layer with a similar strike occurs.

About 110 feet east of the last-mentioned quartzite exposure, on the northern side of the small stream already mentioned, a series of red shale

ridges begins, trending N. 20° E. for a distance of 200 feet. Just north of a wood road the shales strike N. 30° E., with a dip of 85° to vertical. The shales contain nodules of limestone which have yielded a few casts of *Agraulus strenuus.*

The ridges above described terminate at a point just south of the open fields. About 300 feet northwestward, near the western edge of the open fields, occurs locality 2. It is a knoll trending N. 15° W. and consisting chiefly of reddish and greenish shales; lying upon the top and western side of the knoll are great limestone blocks whose position in the section can not be accurately determined, but which have furnished all the fossils cited as coming from locality 2. The bowlders seem to belong to layers in the immediate vicinity, but to have been broken up by the evidently strong folding and shearing of the Cambrian strata in this region.

The following fossils have been found at locality 2: *Obolella atlantica* Walcott, figured but not named in our report; *Obolella crassa* Hall, *Scenella reticulata* Billings, *Stenotheca curvirostra* S. & F., *Stenotheca rugosa* var. *abrupta* S. & F., *Platyceras primævum* Billings, *Hyolithes americanus*, *Hyolithes communis* var. *emmonsi* Ford, *Hyolithes quadricostatus* S. & F., *Microdiscus bellimarginatus* S. & F., *M. lobatus* Hall, *Olenellus walcotti* S. & F. (probably a young form of some known species), *Ptychoparia attleboroensis* S. & F. (probably the young form of some species of trilobite), *Agraulus strenuus?* Billings.

Northwest of locality 2, on the other side of a fence, is another knoll, trending N. 23° E., consisting chiefly of reddish and greenish shales, but containing on the west side a few nodules of limestone which have afforded Hyolithes and fragments of Agraulus.

There is a similarity of trend between the Cambrian deposits at locality 1 and immediately northward, and at the margin of the granite hill immediately to the westward of it. This is also true in a measure of the outcrops south of the stream about 500 feet north of locality 1, and 500 feet south of locality 2, where the quartzite shale and limestone beds strike northeastward, while the granite hill on the west seems to make a similar deflection. Again, at locality 3 and northwestward, the Cambrian strata strike northwestward, apparently following the general trend of the eastern margin of the granite hill.

Quartzite occurs at the southeastern angle of Hoppin Hill, just north-

west of locality 1, in the underbrush, and about halfway between localities 1 and 2 on the west side of the set of exposures already described. The temptation is very strong to consider the quartzite and the associated green shales as forming the lowest beds of the series actually exposed. The limestone beds immediately toward the east of the green shale and associated quartzite layers, containing Hyolithes and Hyolithellus chiefly, at locality 1, and again just east of the green shales and sandstones halfway between localities 1 and 2, could then be considered as forming an immediately overlying horizon, while the beds still farther eastward, containing frequent trilobite remains (*Agraulus strenuus*), might be considered as belonging to a still higher horizon. This would suggest that locality 2 belongs to a horizon slightly higher than locality 1.

About 700 feet north of locality 2 is found a granite boss, the northern margin of which extends northeastward, forming a steep wall. On the northern side of this wall, in close contact with the granite, a small exposure of red shales was unearthed in 1887.

Red shales also occur at various points on the eastern side of the valley in which localities 1 and 2 occur. The general conclusion is that the valley as far as described is underlain altogether by Olenellus Cambrian rocks.

The western side of the valley is bordered by the Hoppin Hill granite boss. On the northeastern side, toward North Attleboro, occurs the second boss, already described, and along the remainder of the eastern side of the valley the Olenellus Cambrian is overlain by the Carboniferous. The most southern Carboniferous exposure north of the east-west Hoppin Hill road and east of the Cambrian area, strike N. 10° W., dip vertical, occurs on the hillside, only 325 feet north of the road leading east down from Hoppin Hill. Another exposure is 250 feet north; a third is 115 feet north, strike N. 40° E.; a fourth is 75 feet north, strike N. 15° E., dip steep west. All of these exposures are conglomerates, in which the pebbles consist of a hard glassy quartzite.

South of the Hoppin Hill road leading eastward are several additional exposures of Carboniferous conglomerate and shale on the east side of the Olenellus Cambrian valley.

The construction of the new railroad through the western part of the village of North Attleboro has disclosed a series of red shales south of the depot, as far as the bend of the road toward the southeast. The

geological position of these shales is unknown. Next the depot and northward occur exposures of arkose, undoubtedly Carboniferous. It is possible, however, that the red shales in question still belong to the Olenellus Cambrian, which is here again overlain by the Carboniferous.

VALLEY OF LOCALITY 3.

The road across Hoppin Hill leads from locality 1, first westward, then southwest, nearly south, then again west until a small stream is crossed. A short distance west of the stream is a house. Along the farm lane to the northward red limestone bowlders appear in the fence wall on the left side of the way. The bowlders increase in frequency as the end of the lane is approached. At the northeastern end of the field, just west of the northern end of the lane, red shale is exposed in the soil. The limestone bowlders probably belong in situ somewhere among the red shales of the vicinity, but at the present time their precise location can not be determined.

The above-mentioned limestone bowlders have furnished the following fossils: *Obolella crassa*, *Scenella reticulata*, *Stenotheca rugosa* var. *abrupta*, *Hyolithes communis*, possibly also *H. communis* var. *emmonsi? Microdiscus bellomarginatus*, and *Agraulus strenuus*. Judging from the fauna alone, locality 3 belongs to the horizon of locality 2, rather than to that of locality 1. No quartzitic layers have been observed in this valley, and the actual exposures, as already stated, are confined to red shales. The Olenellus Cambrian deposits of this valley are bordered on the east by the granite of Hoppin Hill. Toward the northwest occur several granite exposures, evidently connected beneath the soil, and trending approximately north and south. Directly west there are no exposures, but if there be any Cambrian in this direction it is probably overlain by the Wamsutta Carboniferous, which is known to occur considerably farther westward in the valley of Abbotts Run. In this direction arkose, possibly near the base of the Carboniferous, occurs about a mile north of locality 3, on the road from North Attleboro to Arnolds Mills, and is quite abundant eastward as far as North Attleboro. Wamsutta Carboniferous conglomerate occurs also a mile and a half south of locality 3, apparently covering the Olenellus Cambrian in this direction. Red shales occur at various points west and southwest of South Attleboro, but so close to Wamsutta Carboniferous exposures that it is impossible for the present to consider them as of Olenellus Cambrian age. It may, how-

ever, be worth while to call attention to their distribution as recorded in the section of this report which has been prepared by Mr. Woodworth.

LOCALITY 4, NORTHEAST OF DIAMOND HILL.

Along the road from Diamond Hill northward to West Wrentham exposures of granite are met almost immediately on crossing the State line from Rhode Island into Massachusetts. After following the southern margin of the granite hill eastward along the base of the hill for a distance of several hundred feet, a change in direction of the border toward the northeast takes place. Here a number of red limestone bowlders are found on the hillside. Toward the brow of this hill there is a fair exposure of red shales dipping at a high angle westward and striking east of north. West of these, quartzitic beds probably occur, as is shown by fragments in the soil and on the hillside.

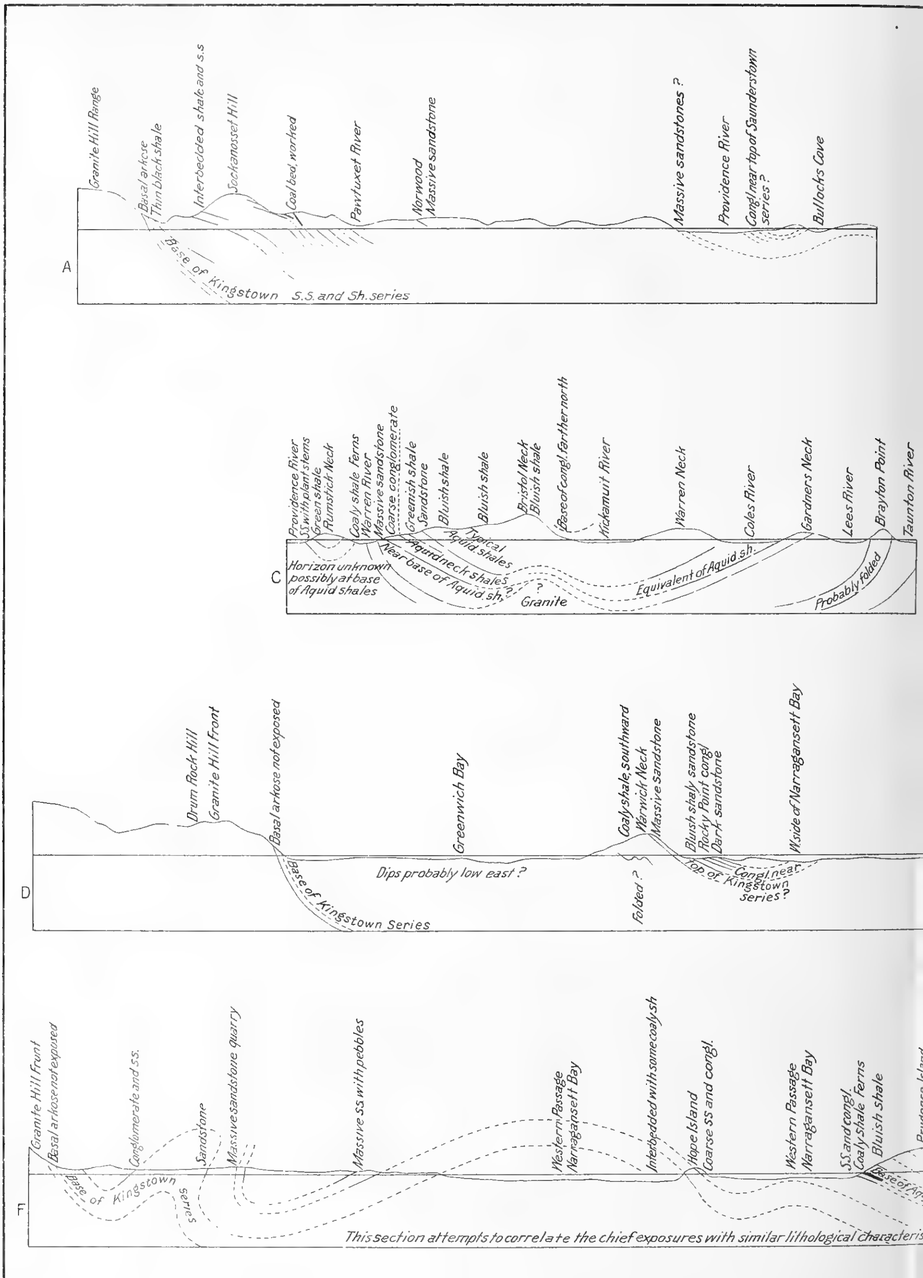
The loose bowlders on the hillside evidently are almost in situ and contain *Hyolithes princeps?* and *Hyolithellus micans?*, suggesting nearer relation with locality 1. From the top of this part of the hill it is a distance of about 100 feet to the border of the granite mass forming the main body of the hill. Along the brow of the hill westward the granite is seen to inclose long thin layers of an argillitic purplish or brownish rock, which may possibly be fragments of Olenellus Cambrian shale hardened by metamorphism. It is impossible to determine from these inclusions whether the granite of these regions is to be considered as pre- or post-Cambrian in age. If the fragmental inclusions referred to be Olenellus Cambrian shales the granite must evidently be considered as post-Cambrian. Post-Cambrian granites are well known in the Quincy region in eastern Massachusetts.

MAPS AND SECTIONS.

The uncertainty which accompanies many of the views regarding the geological structure of the lower Narragansett Basin is largely due to the fact that the greater part of the area is covered by glacial drift and sand plains or concealed by the water of the many arms of the bay. This is well brought out by the map, which indicates the position of almost all outcrops of any value for geological purposes. Moreover, the outcrops are frequently scanty or absent at the very horizons where it is exceedingly desirable to have them in order to determine the question of the succession and the equivalence of the rocks. It was necessary on this account to leave some areas without other indication than the color for the general Carboniferous. The boundaries of some of the divisions recognized may eventually have to be somewhat shifted, as sewers, ditches, and cellars expose rocks now hidden from sight.

Moreover, in order to present anything in the nature of a section across strata, it was necessary to generalize the interpretation of outcrops. A reference to the map will usually indicate the extent to which this has been done.

There is perhaps little doubt that both the Kingstown sandstones and the Aquidneck shales have been considerably folded. This must certainly be true of the Kingstown sandstones between Wickford and Potowomut Neck, and also of the Aquidneck shales from Coddington Cove to Black Point. But unfortunately we have so far no indications as to the precise locations of any of the synclines or anticlines in this system of folding. It therefore seemed impossible to introduce folds into the section, offering possibly a source of even greater error than if these indications were omitted, but the general necessity of assuming folding was brought out clearly in the text. Actual exposures are shown in the sections by solid lines, while inferences as to the continuation of these exposures beneath the soil and the probable attitude of strata where there are no exposures are indicated by dotted lines.



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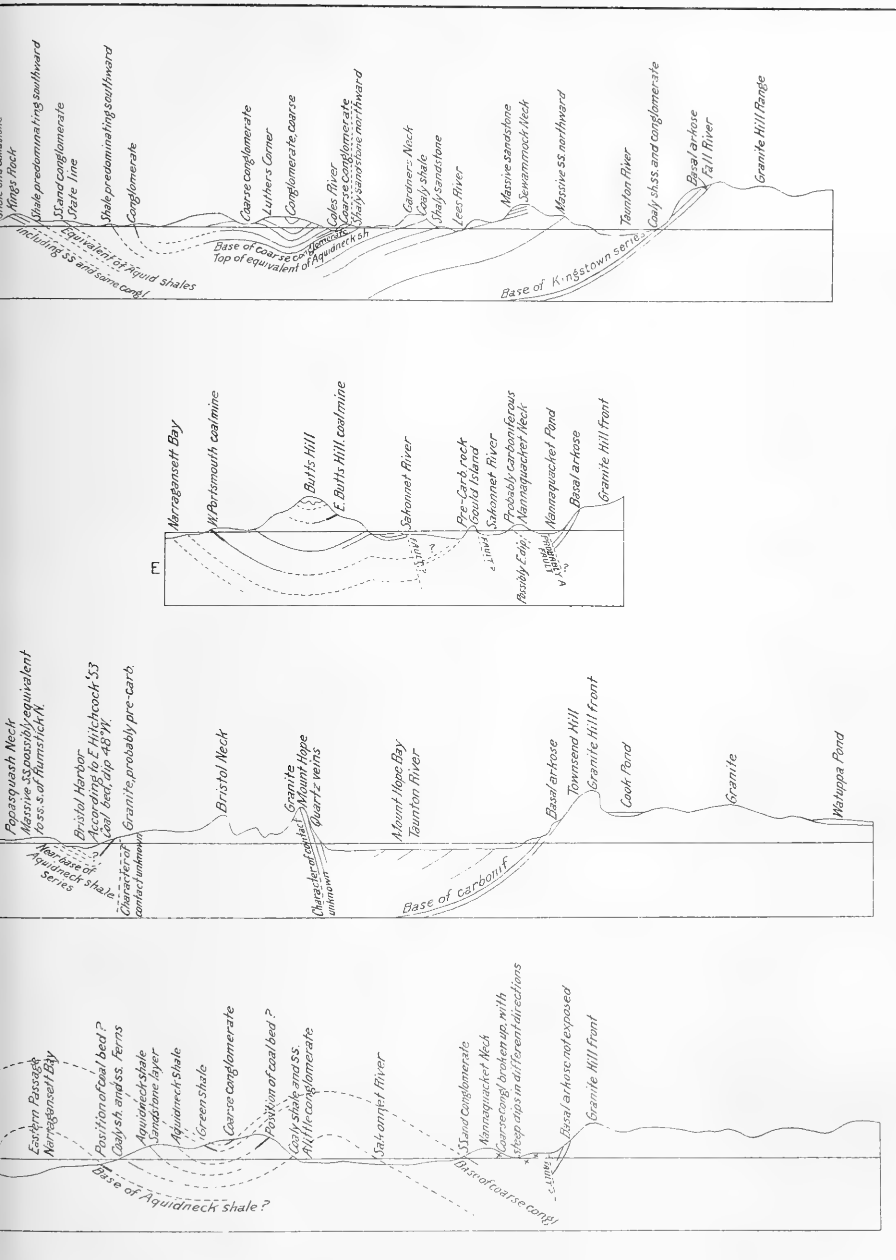

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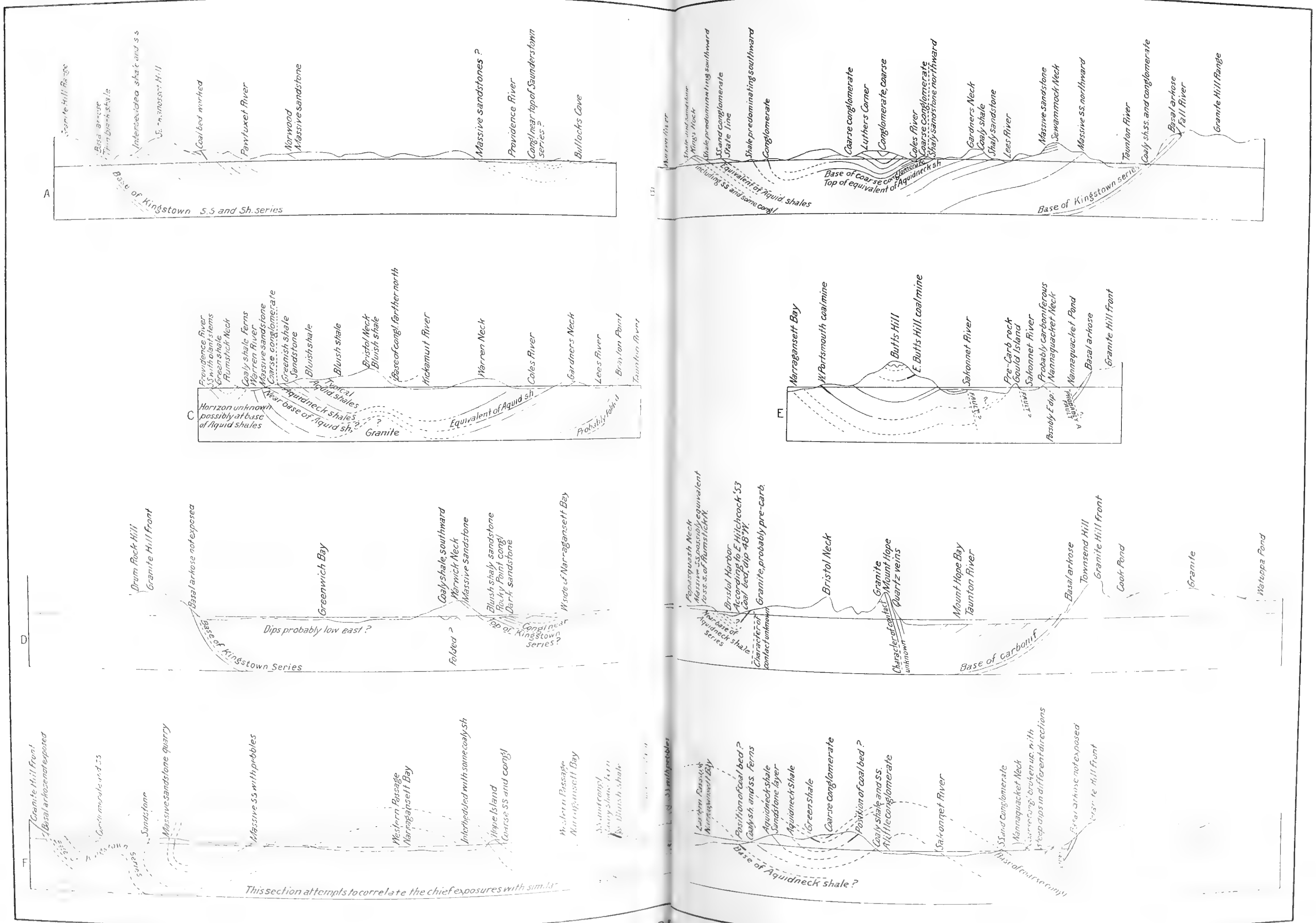
ANSETT BAY REGION



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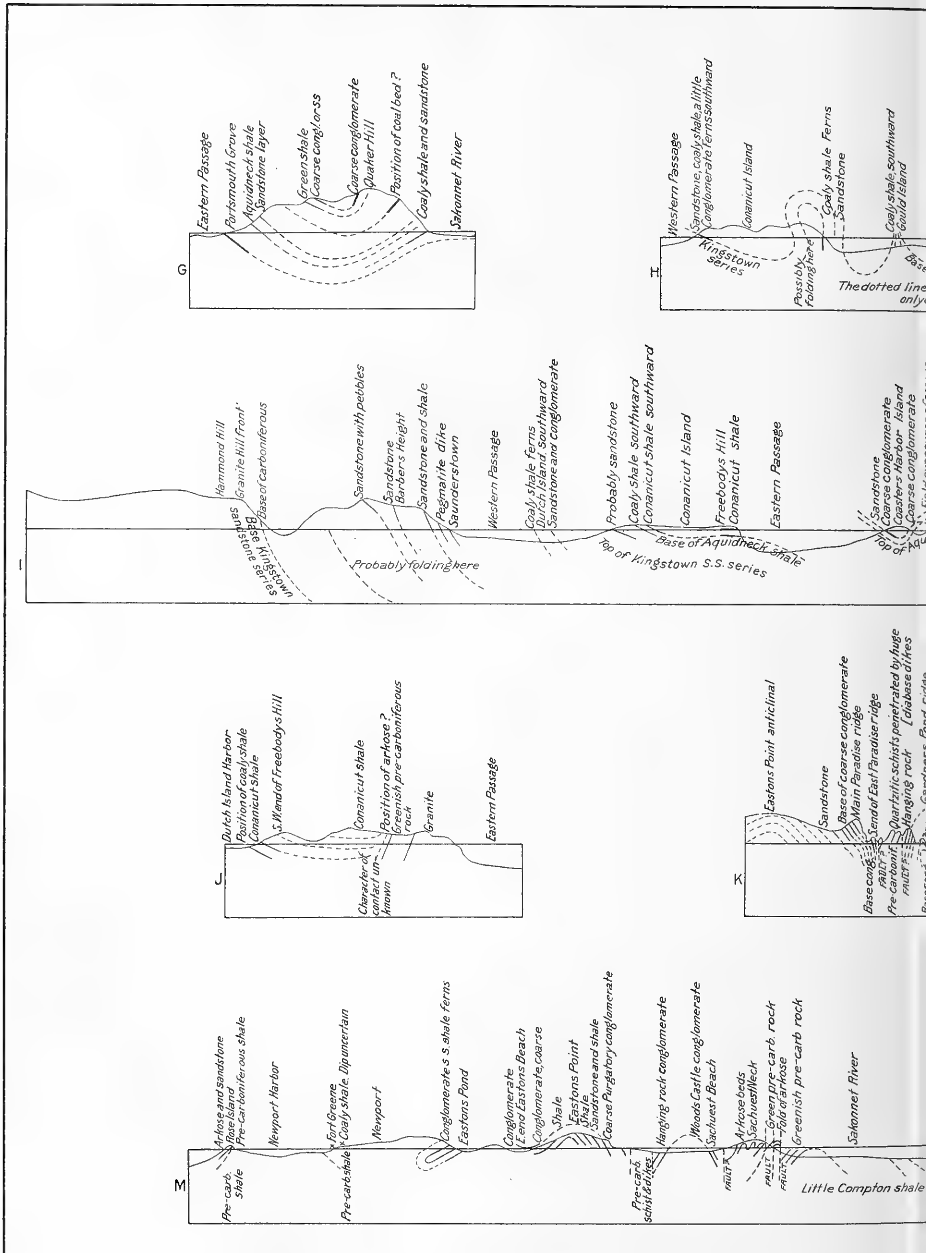

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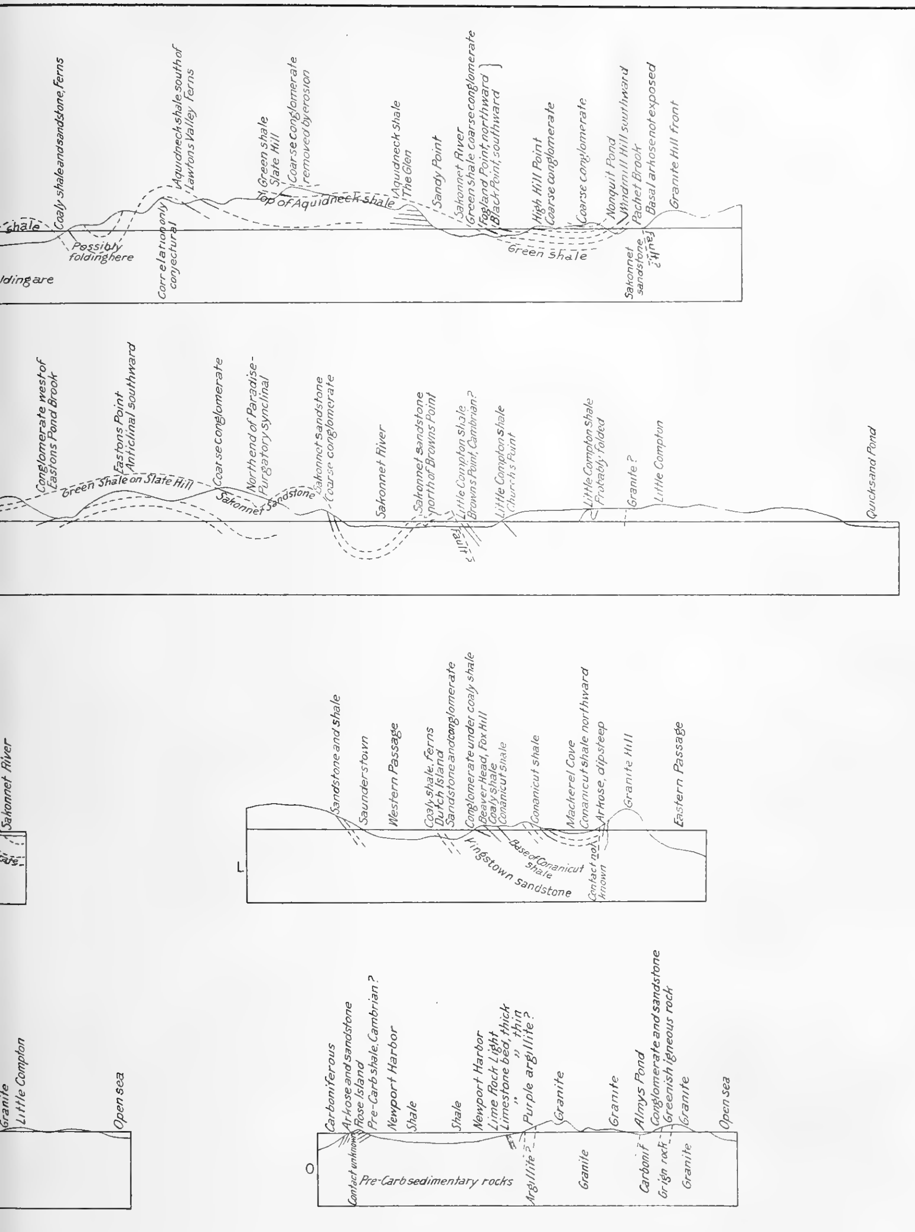

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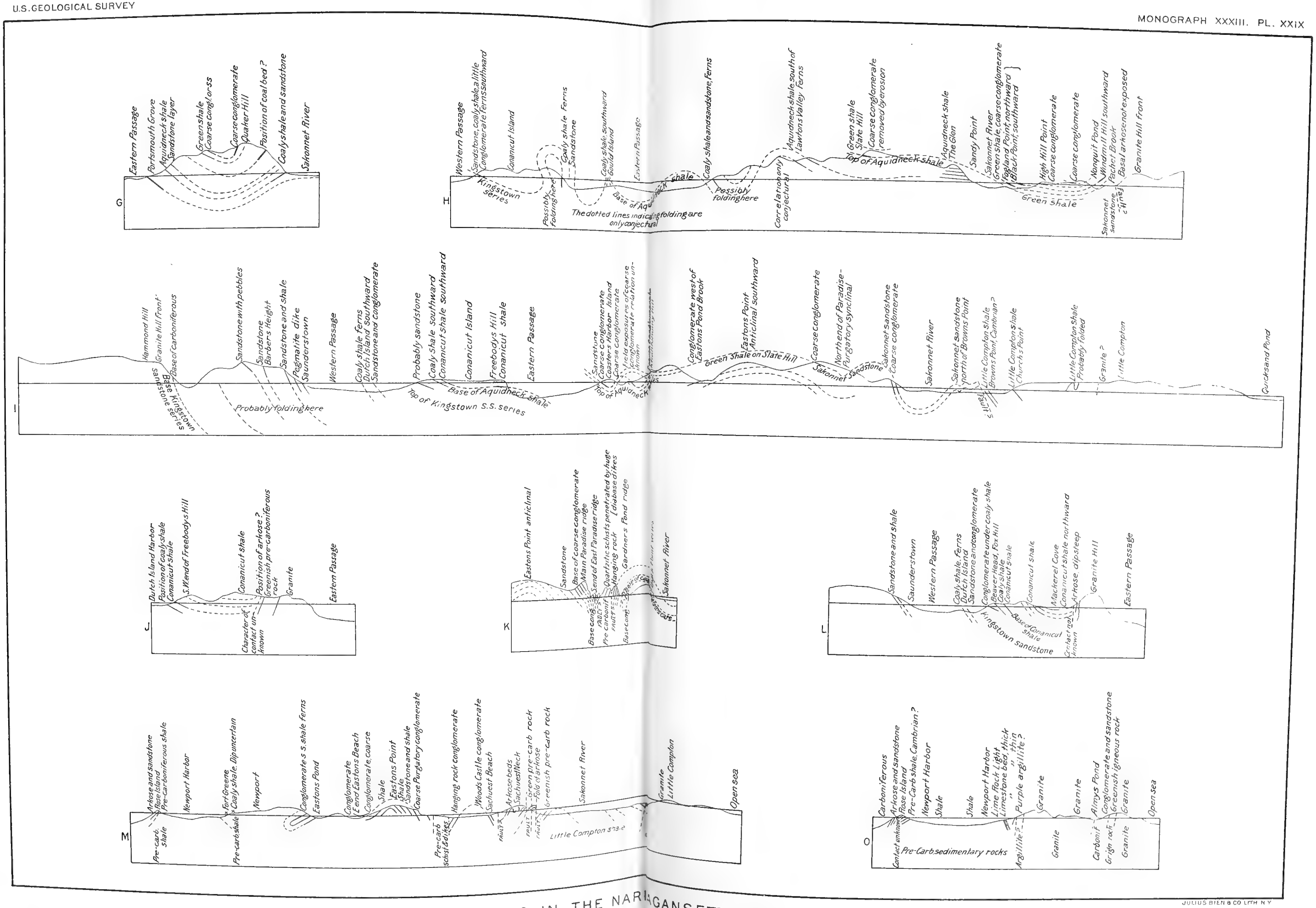

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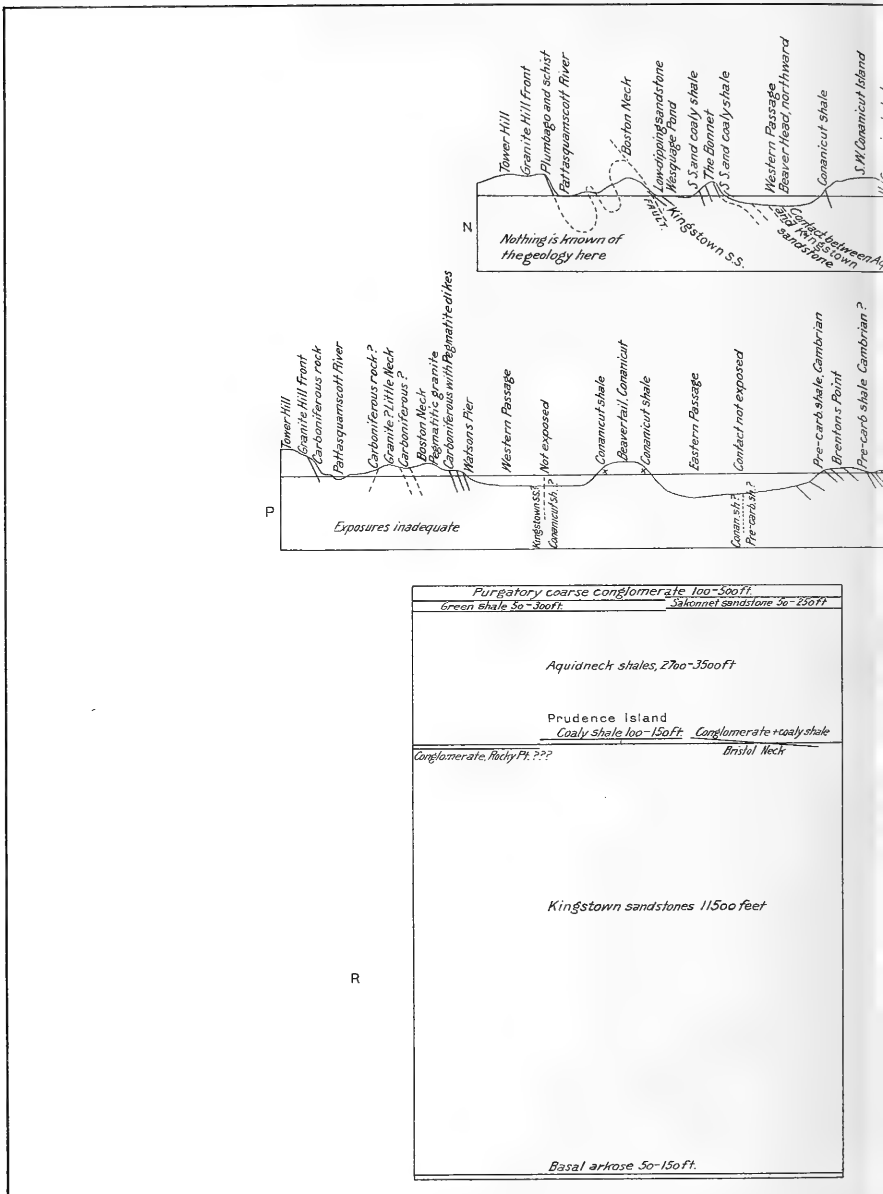

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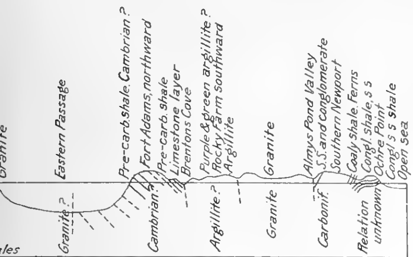

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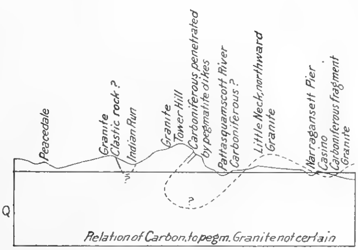

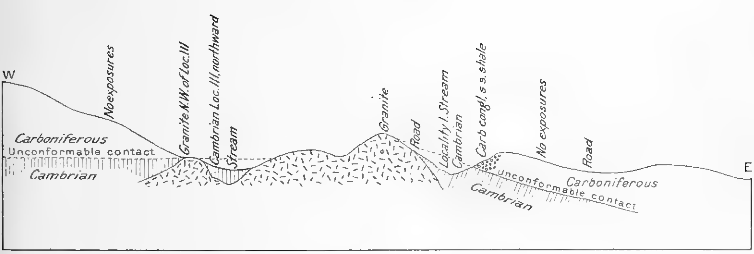

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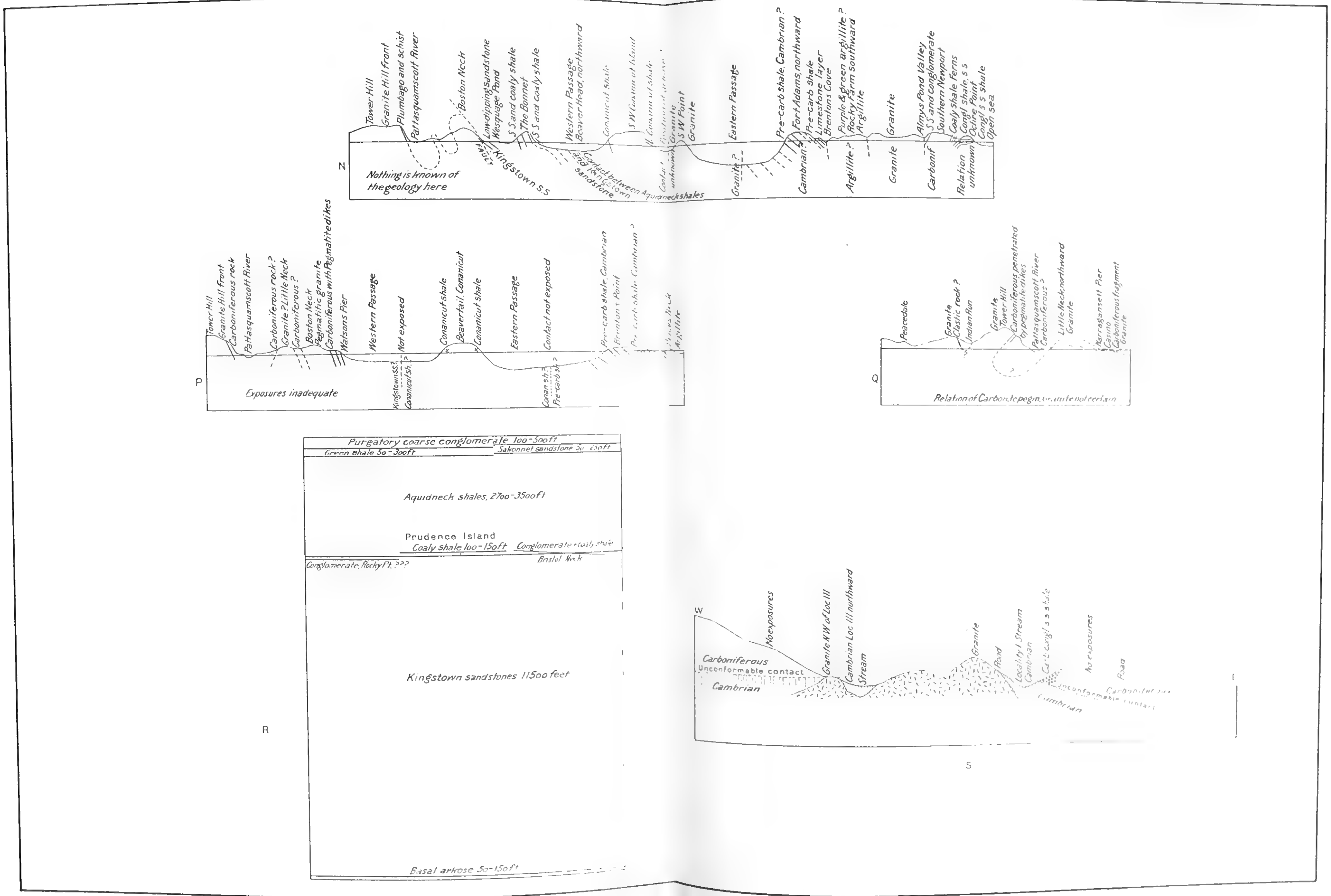
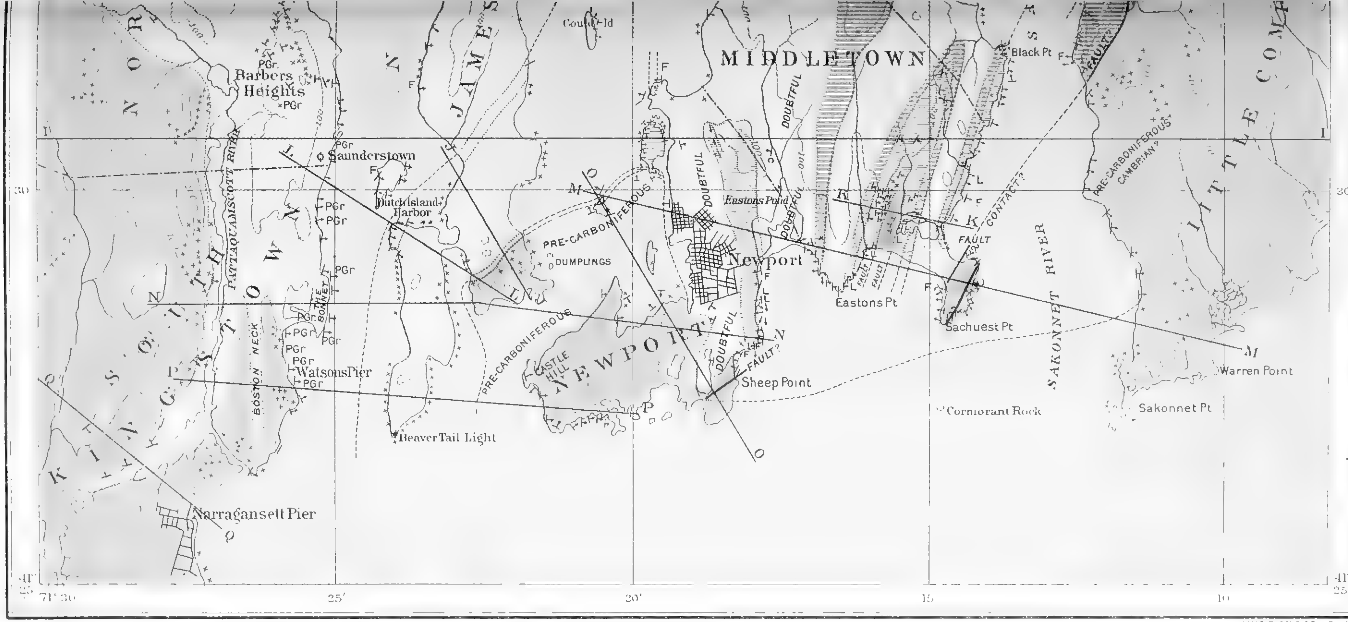


SECTIONS IN THE NARRAGANSETT BAY REGION


CRANSTON
Pawtuxet River
Warwick Pond
WARWICK
RiverView
Rocky Point
GREENWICH BAY
E. Greenwich
Sandy Pt
PART OF WARWICK
POTOWOMUT RIVER
EAST GREENWICH
NORTH KINGSTOWN
Quonset Pt.
Sauga Pt
Belleville Pond
Warwick Light
North Pt
N.W Point
Patience Id.
NARRAGANSETT BAY
Gull Pt
PRUDENCE ISLAND
Hope Id.
North Point Light
BARRINGTON
BARRINGTON RIVER
WARREN
Warren
WARREN R.
BRISTOL
Bristol
HITCHCOCK
KICKAMUIT RIVER
MASSACHUSETTS
RHODE ISLAND
MOUNT HOPE BAY
BOUNDARY LINE
MOUNT HOPE
FAULT
SWANSEA
COLES RIVER
SOMERSET
TAUNTON RIVER
Brayton Point
FALL RIVER
Cook Pond
TIVERTON
Stafford Pond
Sawoy Pond
Hog Id.
Dyer Id
PORTSMOUTH
COAL MINE
Gould Id
FAULT?
SEAKONNET RIVER
Fogland Pt.
Nonquit Pond
71° 30'
25'
20'
15'
10'
41° 45'
40'
35'



GEOLOGICAL MAP OF THE SOUTHERN PART OF THE NARRAGANSETT BASIN

BY AUGUST F. FOERSTE, ASSISTANT GEOLOGIST. N.S. SHALER GEOLOGIST IN CHARGE.

Scale

1 0 1 2 3 4 5 6 7 Miles

LEGEND

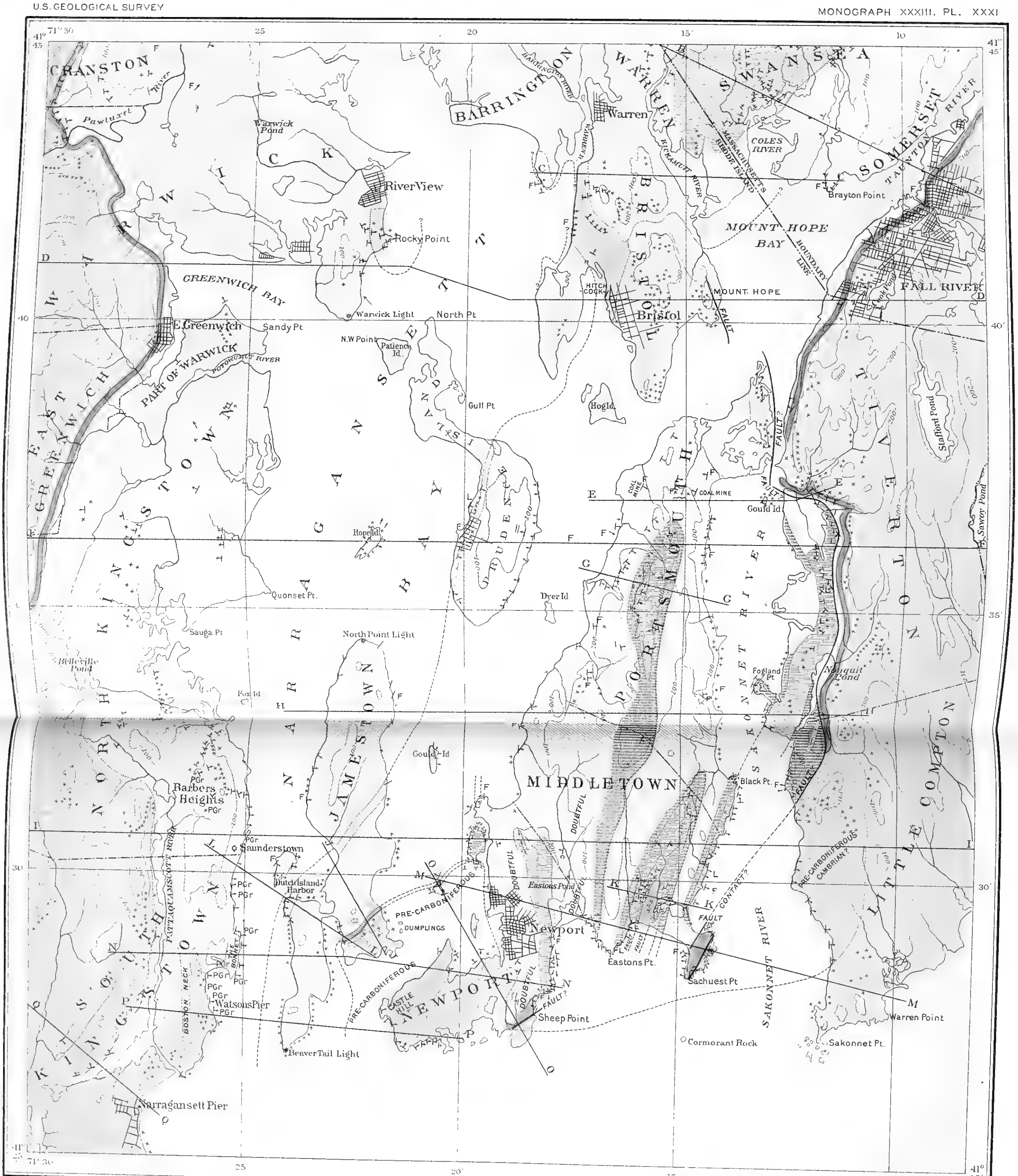
CARBONIFEROUS

Coarse conglomerate — Sakonnet sandstone — Aquidneck shales — Transition rocks between Aquidneck shales and Kingstown sandstone — Kingstown series — Carboniferous Kingstown sandstone and Aquidneck shales not distinguished — Basal arkose often associated with much coaly shale

PRE-CARBONIFEROUS

Granite and other pre Carboniferous rocks not specially investigated or distinguished. — Pre Carboniferous rocks partly argillite, partly of igneous origin not distinguished — Quartzitic schist included in and penetrated by igneous rock masses (coarse diabase ?) in Paradise-Hanging Rock synclinal — Sedimentary rocks (Cambrian?)

⊢ Strike and dip → General pitch ∼ Small folds × Exposures F. Carboniferous fossils, chiefly ferns and stems of plants. PGr The pegmatite granite intrusions from Watsons pier, northwards to Barbers Height. L Fossil oboli in pebbles



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[Monograph XXXIII.]

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8	Sewanee	Tennessee	85° 30′-86°	35°-35° 30′	975	25
9	Anthracite-Crested Butte	Colorado	106° 45′-107° 15′	38° 45′-39°	465	50
10	Harpers Ferry	Virginia West Virginia Maryland	77° 30′-78°	39°-39° 30′	925	25

No.	Name of sheet.	State.	Limiting meridians.	Limiting parallels.	Area, in square miles.	Price, in cents.
11	Jackson	California	120° 30′–121°	38°–38° 30′	938	25
12	Estillville	Virginia, Kentucky, Tennessee	82° 30′–83°	36° 30′–37°	957	25
13	Fredericksburg	Maryland, Virginia	77°–77° 30′	38°–38° 30′	938	25
14	Staunton	Virginia, West Virginia	79°–79° 30′	38°–38° 30′	938	25
15	Lassen Peak	California	121°–122°	40°–41°	3,634	25
16	Knoxville	Tennessee, North Carolina	83° 30′–84°	35° 30′–36°	925	25
17	Marysville	California	121° 30′–122°	39°–39° 30′	925	25
18	Smartsville	California	121°–121° 30′	39°–39° 30′	925	25
19	Stevenson	Alabama, Georgia, Tennessee	85° 30′–86°	34° 30′–35°	980	25
20	Cleveland	Tennessee	84° 30′–85°	35°–35° 30′	975	25
21	Pikeville	Tennessee	85°–85° 30′	35° 30′–36°	969	25
22	McMinnville	Tennessee	85° 30′–86°	35° 30′–36°	969	25
23	Nomini	Maryland, Virginia	76° 30′–77°	38°–38° 30′	938	25
24	Three Forks	Montana	111°–112°	45°–46°	3,354	50
25	Loudon	Tennessee	84°–81° 30′	35° 30′–36°	969	25
26	Pocahontas	Virginia, West Virginia	81°–81° 30′	37°–37° 30′	951	25
27	Morristown	Tennessee	83°–83° 30′	36°–36° 30′	963	25
28	Piedmont	Virginia, Maryland, West Virginia	79°–79° 30′	39°–39° 30′	925	25
29	Nevada City: Nevada City, Grass Valley, Banner Hill	California	121° 00′ 25″–121° 03′ 45″ 121° 01′ 35″–121° 05′ 04″ 120° 57′ 05″–121° 00′ 25″	39° 13′ 50″–39° 17′ 16″ 39° 10′ 22″–39° 13′ 50″ 39° 13′ 50″–39° 17′ 16″	11.65 12.09 11.65	50
30	Yellowstone National Park: Gallatin, Canyon, Shoshone, Lake	Wyoming	110°–111°	44°–45°	3,412	75
31	Pyramid Peak	California	120°–120° 30′	38° 30′–39°	932	25
32	Franklin	Virginia, West Virginia	79°–79° 30′	38° 30′–39°	932	25
33	Briceville	Tennessee	84°–84° 30′	36°–36° 30′	963	25
34	Buckhannon	West Virginia	80°–80° 30′	38° 30′–39°	932	25
35	Gadsden	Alabama	86°–86° 30′	34°–34° 30′	986	25
36	Pueblo	Colorado	104° 30′–105°	38°–38° 30′	938	50
37	Downieville	California	120° 30′–121°	39° 30′–40°	919	25
38	Butte Special	Montana	112° 29′ 30″–112° 36′ 42″	45° 59′ 28″–46° 02′ 54″	22.80	50
39	Truckee	California	120°–120° 30′	39°–39° 30′	925	25
40	Wartburg	Tennessee	84° 30′–85°	36°–36° 30′	963	25
41	Sonora	California	120°–120° 30′	37° 30′–38°	944	25
42	Nueces	Texas	100°–100° 30′	29° 30′–30°	1,035	25
43	Bidwell Bar	California	121°–121° 30′	39° 30′–40°	918	25
44	Tazewell	Virginia, West Virginia	81° 30′–82°	37°–37° 30′	950	25
45	Boise	Idaho	116°–116° 30′	43° 30′–44°	864	25
46	Richmond	Kentucky	84°–84° 30′	37° 30′–38°	944	25
47	London	Kentucky	84°–84° 30′	37°–37° 30′	950	25
48	Tenmile District Special	Colorado	106° 8′–106° 16′	39° 22′ 30″–39° 30′ 30″	55	25
49	Roseburg	Oregon	123°–123° 30′	43°–43° 30′	871	25
50	Holyoke	Massachusetts, Connecticut	72° 30′–73°	42°–42° 30′	885	25

STATISTICAL PAPERS.

Mineral Resources of the United States [1882], by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

Mineral Resources of the United States, 1885. Division of Mining Statistics and Technology. 1886. 8°. vii, 576 pp. Price 40 cents.

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In compliance with this legislation the following reports have been published:

Mineral Resources of the United States, 1894, David T. Day, Chief of Division. 1895. 8°. xv, 646 pp., 23 pl.; xix, 735 pp., 6 pl. Being Parts III and IV of the Sixteenth Annual Report.

Mineral Resources of the United States, 1895, David T. Day, Chief of Division. 1896. 8°. xxiii, 542 pp., 8 pl. and maps; iii, 543–1058 pp., 9–13 pl. Being Part III (in 2 vols.) of the Seventeenth Annual Report.

Mineral Resources of the United States, 1896, David T. Day, Chief of Division. 1897. 8°. xii, 642 pp., 1 pl.; 643–1400 pp. Being Part V (in 2 vols.) of the Nineteenth Annual Report.

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Author.

Shaler (N. S.), **Woodworth** (J. B.), and **Foerste** (A. F.)
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